Developing a framework for understanding sociotechnical routes to unintended consequences in Internet of Things (IoT) systems: A case study of an IoT parking solution in a Smart City

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Dedication

Daniel, my husband, deserves the lion’s share of my gratitude for his abundant support and patience during this effort, while also suggesting when it was time to “take a break”. I am incredibly thankful for the gifts that I received from my mother, father, and grandparents. My family members have (had) remarkable character traits and standards that I aspire to live up to as best as I can: being ‘arbeitssam’ (German for ‘hardworking’), curious, determined, communicative, uncomplaining, adventurous, tough, and exact.

An integral part of this project is a case study that I conducted in Santander, Spain. That city welcomed me with open arms when others declined or did not respond. I am grateful to the people of Santander and the experts in the Smart City ecosystem who freely gave of their time.

The help and support of my supervisors, Dr Vaughan Michell, and Professor Jane McKenzie, cannot possibly be overestimated. Both are phenomenal experts in their respective fields within different scientific paradigms. Thus, meetings and calls with a Mechanics and Robotics Engineer and a Professor of Management Knowledge were always thought provoking and invigorating. Their unique ‘world views’ provided the impetus for this work’s paradigmatic blend: Critical Realism as an ontology combined with Relativism as the epistemology.

Professor Roy Bhaskar, who is widely regarded as the initiator of Critical Realism, passed away in 2014. I believe that the scientific community is eternally indebted to him for his many books, articles, and lectures on the subject. My appreciation extends to the larger faculty and staff of University of Reading (Henley Business School) and University of Toronto. It was such a privilege to walk with my friends in the student-cohort on this (at times) stony pathway over the past eight years.

We are all products of our environment and so I thank my extended family, my friends, current and former co-workers, and everybody else who provided encouragement and support.

Clifford James Geertz said: *“There is an Indian story – at least I heard it as an Indian story – about an Englishman who, having been told that the world rested on a platform which rested on the back of an elephant which rested in turn on the back of a turtle, asked (perhaps he was an ethnographer; it is the way they behave), ‘What did the turtle rest on?’ – ‘Another turtle.’ – ‘And that turtle?’ – ‘Ah, Sahib, after that it is turtles all the way down.’ Such, indeed, is the condition of things.”* (1973: 28-29).

It has been a highlight of my life to study at Henley, to research and write this thesis, and to trace down turtles.

Manfred Boudreaux-Dehmer, Brussels, Belgium, August 31, 2022

Declaration

I confirm that this is my own work and that the use of all material from other sources has been properly and fully acknowledged.

Abstract

This thesis explores unintended consequences resulting from the use of Internet of Things (IoT) technology systems. It does this through a Critical Realist (CR) lens, which assumes a stratified ontology that distinguishes the deep generative mechanisms formed in the interaction between powers and tendencies inherent in structures and agency. The observable empirical experiences of matter and meaning contribute to uncovering the complex effects that these generative mechanisms produce, which in turn allow inferences as to their causality. The thesis utilizes examples of IoT use as applied in car parking solutions in a Smart City that were collected as part of a case study.

The first contribution progresses theoretical development through the creation of a Sociotechnical Behavioural Framework (SBF) that abductively infers the mechanisms causing unintended consequences by modelling the paths to events that arise through the systematic interaction between the three sociotechnical domains of Material Agency, Human Agency, and Interpretive Schemas. The SBF is laid out in a Venn diagram where each sociotechnical domain is depicted by a circle with interconnections and with all three circles overlapping at the centre. This central three-way intersection represents an emergent property beyond purely technological effects. The powers and tendencies of the three domains of human and technology interaction produce the deep constitutive entanglement that is described in the theory of Sociomateriality (Orlikowski and Scott, 2008). As a first step, the framework analyses the sequence of interaction loops of designed and intended pathways between the three sociotechnical domains. In a second step, the work draws upon Affordance Theory and Analytical Dualism (Archer, 2010) to separate, temporally and analytically, the contribution of individual components to the recursive relationship between the practice of Material Agency, Human Agency, and Interpretive Schemas. By modelling the variations between expected and actual inputs, it becomes possible to identify the unexpected outputs and unintended consequences that arise from the interplay of the three domains. The framework can be used to analyse actual recorded examples of unintended consequences and to potentially predict future problems. It advances relevant theory by connecting the underlying roots of Sociomateriality (Orlikowski, 2000) with Affordance Theory (Gibson, 2014) and Analytical Dualism (Archer, 2010) as a route to understanding morphogenesis (i.e., the way a system changes) over time.

The second contribution, in line with the work's onto-epistemology of Critical Realism, consists of the retroductive testing of the abductive framework. This provides practical learnings and improvement suggestions through a case study using data from an actual IoT-based car parking system within the Smart City of Santander, Spain. Data collected from system

designers, operators, city officials, and parking system users facilitated the identification of expected outcomes through process flow charts. The comparison between intentions and observations resulted in the identification of 30 routes leading to unintended consequences. These were classified and studied using the SBF to identify their properties, and through reasoning for their occurrence, allowed the suggestion of their generative mechanisms. Testing the framework in this way adds to the knowledge of the sociotechnical design and suggests improvement opportunities in comparable contexts. The newness of the technology, its actual availability in cities, time, and complexity, limited this exploratory case study to one detailed example. The transferability question of the single case study is strengthened in two ways: by utilizing input from actual users of the technology to understand the generative mechanisms in more depth, and through a thought experiment that is included in the thesis.

The final and third contribution concerns the application of findings as a series of recommendations and a methodology to identify how the new framework could be used in practice to limit the occurrence of unintended consequences in sociomaterial systems and/or to analyse their causality and hence improve IoT and other system designs. The value of the framework lies in the fact that it offers a logical and structured way for considering where disconnects in assumptions and intentions of policy makers, business analysts, project managers, developers, users, and other stakeholders could produce unintended consequences in the development of complex systems involving sociomaterial interaction. It can provide an opportunity for advanced consideration of the potential risks that may otherwise be overlooked in phased handovers between stakeholder communities.

There is an opportunity for future research to explore the use of the SBF beyond the context of IoT in a Smart City, once IoT technology becomes more widely implemented and user experience data becomes available. This could be accomplished through a Critical Realist study in which the identified generative mechanisms are retrodictively assessed and either validated or adjusted. Such an attempt at extending the SBF's generalizability could take place in a different sociotechnical setting within the realm of the IoT or in other emergent and disruptive technologies.

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Glossary

Term	Definition
3-D (Printing)	Three-dimensional Printing – construction of an object from a computer animated model or digital 3D drawing
Actor-Network Theory	Elevates non-human actors in an equal engagement of reassembling the social in that they are entangled with the social practice in which they are used
Actuator	Conversation of an electronic input signal into physical action (the opposite of a sensor) – examples are remote controlled locks, valves, switches, etc.
Affordance	Property of an inanimate object that allows a user to perform an action within a given range of possibilities (versus Constraint)
Agential Realism	Advocates the ontological inseparability of intra-acting universal phenomena, such as Human Agency and Non-Human Agency
AI	See Artificial Intelligence
Analytical Dualism	Argument that while structure and agency are interdependent in a duality, they operate on different timescales and can therefore be analysed separately. Analytical Dualism can thus provide insight into Critical Realism's unobservable structures and illustrate their internal causal dynamics.
ANT	See Actor-Network Theory
Artificial Intelligence	Concept within computer science where software is able to analyse its environment with pre-determined rules, search algorithms, or pattern recognition – AI mimics biological intelligence in that the software acts with varying degrees of autonomy
Autonomous Vehicles	Self-driving or driverless car
Big Data	Means to systematically extract information from structured or unstructured data that are otherwise too large or complex for processing via traditional computing methods

Term	**Definition**
Cartesian Dualism	Division of reality into two independent principles: mind and matter
Constraint	Property of an inanimate object that limits the range of possible use (versus Affordance)
Critical Realism	Branch of philosophy that distinguishes between what is 'real' and what is 'observable'. The former cannot be observed and exists independently from human perceptions, theories, and construction. These unobservable structures cause observable events – the aim of science should therefore be to uncover 'real' structures that are a prerequisite to understanding the world. Analytical Dualism can aid in illuminating Critical Realism's unobservable structures and illustrate their internal causal dynamics.
Data Model	Logical inter-relationships and data flows between data elements – including documentation about their storage, processing, and retrieval
Drone	Unmanned aerial vehicle
Duality of Structure	Acceptance that structural properties of social systems are both the medium and the outcome of practices that constitute those systems
Effectivity	See Human Agency – essentially 'human affordances'
Emergence	Process by which an emergent property arises where the consequences are more than the sum of its parts (could also include the description of how the parts may explain the emergent behaviour)
Emergent Property	Result of several simple entities (agents) operating in an environment where complex behaviours are formed as a collective – examples in biology are the shape and behaviour of a flock of birds or school of fish
Entanglement	Foundational onto-epistemic commitment of inseparability of matter and meaning

Term	**Definition**
Human Agency	Abilities, skills, disposition, personal routines, or attitudes of human beings
Imbrication	Changing user perceptions (of technology) through recurrent and episodic interactions with this technology and how these interactions explain the emergent whole
Intelligent Parking Assistant (IPA) Systems	Open system based on sensors in city streets to track real-time availability for users to access this information via a mobile device
Intelligent Parking Reservation (IPR) Systems	System typically used in parking garages (often in a closed-loop fashion) to enable users to find a parking space
Internet of Things	System of interrelated sensors and actuators with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction
Interpretive Schema	Norms, rules, laws, designs, or standards that establish general societal (Human Agency) or technical (Material Agency) expectations
IoT	See Internet of Things
Machine-to-Machine (M2M) Communication	Data exchange between two machines without human intervention via wireless (sometimes wireline) communication – often seen as a precursor to the Internet of Things (IoT)
Material Agency	Properties of inanimate objects that allow a user to perform an action (Affordance) or limit the range of possible use (Constraint)
Morphogenesis	Greek for ‘beginning of the shape’: Originally from biology, but also a component of general systems theory where processes elaborate or change a system’s given form, structure, or state (opposite of morphostasis)
Near Real Time	Near Real Time computing (opposite of ‘batch processing’) where data is collected, and information is available with only minimal time delays

Term	Definition
Non-Human Agency	See Material Agency
Norm	Vehicle to guide behaviour of a person or usage of an object in a technical, formal, or social (informal) setting
NRT	See Near Real time
Robotics	Research at the intersection between computer science and engineering involving design, construction, operation, and use of robots
SBF	See Sociotechnical Behavioural Framework
Sensor	Device that detects and transmits a change in the environment (temperature, humidity, pressure, presence, or absence of an object, etc.)
Smart City	City that utilizes Internet of Things (IoT) sensors and artificial intelligence to collect data and gain insights to better manage assets, resources, and services with the aim to enhance the quality of life for its residents and visitors
Smart Computing	New generation of integrated hardware, software, and network technologies that provide IT systems with real-time awareness and advanced analytics to help people make more intelligent decisions
Social Determinism	Represents the view that technology usage is prompted by cultural and social structural patterns of societies
Sociomateriality	Promotes the unpredictable und unstable entanglement between material (technological), human, and normative (structural/interpretive) manifestations that results in the complete fusion of all three
Sociotechnical Behavioural Framework	Enables improved examination of human behavioural consequences in a socio-material system, initially developed from the literature review in Chapter 2 of this thesis

Term	Definition
Stratification	Ontological commitment within Critical Realism to a stratified reality (real, actual, and empirical)
Structural Elaboration	Reproduction (morphostatic) or transformation (morphogenetic) of antecedent structures
Structuration	Connection between Human Agency and norms for building duality between the material and human sides
Structure or Social Structure	Institutionalized norms, rules, laws, standards, designs, and expectations
Structured Data	Data with a pre-defined data model or 'schema' that make them easily addressable for retrieval or reporting (dates, numbers, keys stored in a database) – opposite of Unstructured Data
Technological Determinism	Represents the view that technology shapes organizations and society
Traffic Modal Split	Ratio (or percentage) of travellers using transportation types such as walking, automobiles, bicycles, buses, trains, etc.
Unstructured Data	Data without a pre-defined data model that is therefore not easily categorizable or searchable (free text, audio video, social media postings, etc.) – opposite of Structured Data

1 Introduction

"There are no general theories about everything." (Tan et al., 2008: 43)

The main goal of this thesis is to progress theoretical development on the basis of a framework to systemically think through implications in conceptualizing, planning, constructing, and implementing Internet of Things (IoT) systems within the context of a Smart City. The aim is to identify unintended consequences (UCs) of the use of this technology and to establish their likely causes through rigorous inference. This helps in predicting future problems early in the planning process so that corrective actions can be taken that increase the probability for a successful roll-out. As a practical contribution, the case study that was explored to inform and assess the workings of this framework provides hands-on learnings for Smart Cities in comparable contexts. As a second practical aid, the work closes with possible recommendations for cities to avoid UCs in similar settings.

The thesis contributes to the study of a complex and systemic phenomenon which has macro level implications for societal development and that is central to the academic challenge of examining how structure and agency interact over time in such systems.

1.1 The context of the problem: transforming cities into Smart Cities

"Only a god or a beast could live alone." — Aristotle (Talisse and Goodman, 2007)

The steep increase of urbanization over hundreds of years brought profound changes to every phase of social life where cities have become large, dense, and permanent settlements of heterogeneous individuals (Wirth, 1938: 1) and where these new urban centres are bounded by trade and services rather than agriculture (Weber *et al.*, 1958). This is powered by enormous economic possibilities resulting in more than half of the world's population living in urban areas today with the projection being that virtually the entire global population growth over the next 30 years will be concentrated in urban regions (Programme, 2008). Two prime examples of this trend are the emerging economies of India and China, where large-scale migrations of the populace lead both countries from agricultural and industrial to post-industrial economies. But, this tendency is also present in highly industrialized nations – 82% of the UK population live in urban centres (Saint, 2014: 73) and 76% of countries in the 'very high human development' category find themselves with more than 70% of their citizens residing in urban areas (Programme, 2014). More than half of the world's population is living in cities today with a predicted rise to over 70% by the year 2050 (Affairs, 2013).

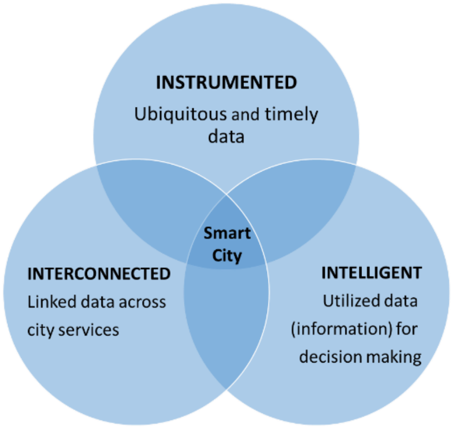
Human settlements have changed over time from simple conglomerates that facilitate safety, comfort, and ultimately survival, to rapidly growing technologized urban centres that utilize distributed data collection mechanisms and advanced IT capabilities for the improved delivery of services. The effective usage of such capabilities gives rise to the concept of a 'Smart City' – with 'smart' being an anthropomorphism of a city acting 'smartly' or 'intelligently' in responding to its challenges by using Natural and Artificial Intelligence embedded in its Information Systems (Liotine *et al.*, 2016: 2935). Where Natural Intelligence systems *evolved* over time, Artificial Intelligence systems are *designed* and branch into human-like thought processes such as learning, reasoning, and self-correction (Kok *et al.*, 2009: 2).

Smart Cities aim to create efficiencies, improve sustainability, advance economic development, and enhance the quality of life for its residents and visitors (Ramaprasad *et al.*, 2017: 14). While technology in general, or even humans without technology, could achieve some efficiencies and economic development, Smart Cities require a level of technological sophistication where the system can sense and model its environment and make decisions. This leads to the need for sensors and for these sensors to be connected in a wide-spread network. Smart Cities 'sense' and 'act' in an instrumented and interconnected fashion (Bowerman *et al.*, 2000) and become intelligent through awareness of massive amounts of data (Marsá-Maestre *et al.*, 2008). The capture and processing of this data occurs through Internet of Things (IoT) technologies that form the underlying building blocks of such instrumentation, interconnection, and intelligence.

It is crucial for cities to become more efficient in using their resources to cope with the amplified demand on services by its residents (Bugliarello, 2006: 25) and address resulting problems such as waste management overload, resource scarcity, increased air pollution, risks to human health, traffic congestion, and generally deteriorating infrastructure (Chourabi *et al.*, 2012: 2289). Governments, businesses, and communities increasingly rely on smart computing technologies to overcome these challenges by connecting critical city infrastructure components and services such as city administration, e-government, education, social, healthcare, public safety, building and urban planning, intelligent transportation systems, and energy and water management applications (Washburn *et al.*, 2009: 1) and (Piro *et al.*, 2014: 169). This can be accomplished through increased automation and robust human-technology networks that advance safety, employment, comfort, mobility, and community for their citizens.

The Internet of Things represents such a robust network in that it embraces everyday objects via sensors in the <u>real</u> world. These objects are connected to the <u>virtual</u> world where the incoming 'raw data' is put into context in the substantial value-add of 'digitally upgrading' conventional objects with digital capabilities (Mattern and Floerkemeier, 2010: 242-243).

Figure 1.1 – Smart City Dimensions



(Harrison et al., 2010)

Figure 1.1 shows the interrelation of a Smart City becoming **instrumented**, **interconnected**, and **intelligent** (Harrison *et al.*, 2010: 1). The interaction between these dimensions resembles a system where the feedback scheme makes evaluative decisions and dynamically 'manages' a situation (Von Bertalanffy, 1973: 6) through the designer's attempt to exert control. This intent to control will be met by varying degrees of a user's adherence to the design that in turn leads to intended and unintended consequences in a dynamic and open system.

One understandable example of technology used to control a city environment is the modulation of price based on fluctuations in demand. Such smoothing of demand 'peaks and valleys' takes place, for example, in San Francisco where a system decides to dynamically increase parking rates on streets with space shortages (Pierce and Shoup, 2013: 67). The micro-economic inverse relationship of a rising price is then expected to depress demand and/or entice potential customers to utilize surrounding areas with more parking availability. The system could also flag longer-term solutions to chronic parking space shortages, for example by suggesting the construction of a new parking garage. This *system of systems*, spanning across technology and humans, is an emergent property, meaning that it is more than the sum of its parts, that has the capacity to alter the provision of city services based on the behaviour of citizens for the optimal use of resources (Harrison *et al.*, 2010: 1:7). While less concentrated car parking across larger and distributed areas may be the intended outcome of system designers and city administrators, the actual behaviour of users could lead to unintended consequences. As an example, since the introduction of dynamically set parking rates, San Francisco has experienced widespread abuse of disabled parking placards that enable users to park at meters for an unlimited time at no cost (Pierce and Shoup, 2013: 78).

Smart Cities thereby *smartly* employ technology to find new efficiencies, save cost, positively affect the environment through reduced energy consumption and greenhouse gas emissions (Doran and Daniel, 2014: 61), and attempt to maintain or enhance the quality of life or attract human and financial capital into cities (Harrison *et al.*, 2010: 1:12).

1.2 The contribution and challenges of IoT technologies

"Imagine things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts." (Commission, 2008)

IoT can be described as a network of uniquely identifiable and interconnected everyday objects with the ability to communicate with each other, often wirelessly, through a standard protocol. These objects support a Smart City's instrumentation requirement via sensors (devices that capture a condition such as an open or closed gate, temperature, pressure, the presence/absence of gases or pollution levels, etc.) and actuators (devices that perform an action such as electric motors or hydraulic mechanisms to open or close a gate, adjust air flow, etc.) The network of IoT devices facilitates Smart City interconnectivity by capturing events near-real-time (NRT) and transmitting them to a central computer where meaningful and actionable information can be derived via complex analytics to take subsequent corrective or predictive, in other words *intelligent*, measures with the use of actuators (Emmerson, 2010: 19).

The term Internet of Things (IoT) was originally used by Kevin Ashton (2009) with the key message being that all initial data on the Internet have been created by humans in spite of people having limited time, attention span, and propensity for details. However, our environment is physical, and our economy, society, and ultimately our survival, are based on physical things. IoT is part of the current generation of technology that draws a line from the first industrial revolution with Thomas Newcomen's invention of the steam engine in 1712 that enabled mechanical production powered by water and steam. The line then continued through the advent of electricity that facilitated mass production and electronics/information technology that enabled the automation of these production capabilities in, respectively, the second and third industrial revolution cycles. We have now entered the phase of the fourth industrial revolution where the velocity, scope, systems impact, disruption to almost every industry, and the creation of massive amounts of digital content has no historical precedent. The differentiation between the physical, digital, and biological spheres are increasingly blurring as developments occur at break-neck speed (Schwab, 2017: 1) that are fuelled by an ever-decreasing cost of computing storage and power, processor sizes, and advancements in battery technology (Commission, 2008). This instance of the industrial revolution is made up of Artificial Intelligence (AI), Big Data, Robotics, Drones, Autonomous Vehicles, 3-D, and IoT in the presence of computing power that can virtually track and count everything and connect vast amounts of data. These sensors and computers have the potential to bypass human limitations where at some point in the future they might "see, hear, and smell the world"

(Botterman, 2009). In the wake of this, the technological potential gives rise to the occurrence of unintended consequences.

Over the past years, IoT has quickly furthered silo-like Machine-to-Machine (M2M) communication solutions to interconnected networks that are used for advanced applications (Olavsrud, 2015: 1) across a variety of industries and functional areas: consumer electronics (wearables, gadgets), automotive solutions (vehicle emergency and entertainment services), environmental (pollution, air, water, soil), healthcare (monitoring, fitness), process industries (robotics, manufacturing, automation), utilities (water, gas, oil, waste), and infrastructure (building maintenance, homes, roads) (Höller, 2014: 16).

An example of an IoT-enabled system would be a network of temperature sensors that are distributed throughout a building or an entire office park. The system dynamically controls air conditioning or heating through a central computer that adjusts based on individual temperature readings. The system could also, if the temperature were to exceed a pre-defined threshold, such as through a fire, automatically alert the fire department via the Internet by giving them the precise location of the emergency and/or trigger the sprinkler system via an actuator. Another example in healthcare is the ongoing monitoring of a pacemaker's performance that is attached to a person's heart. The IoT device could directly dispatch an ambulance in case of a cardiac emergency or alert the doctor's office if there is a maintenance issue such as low battery power.

IoT devices and networks have drastically increased over the past years and the marriage of technological advancements with increasing demand is likely to result in near-ubiquitous IoT presence with market size estimates soaring to 50 billion connected devices by the year 2020 (Ericsson, 2011). However, actors (users, designers, etc.) in this rapidly growing technology realm encounter consequences that may be expected (intended) or surprising (unintended) where the definition of these two distinctly different outcomes is elaborated on in the next section.

1.3 Anticipating the unexpected: the problem of diagnosing intended and unintended consequences

"We are terrible at distinguishing signal from noise." (Silver, 2012: 8)

The American sociologist Robert Merton (1936: 895-901) defined intended consequences as anticipated outcomes following purposive (deliberate) action where an actor chooses, based on motives, from a set of alternatives. By their very nature, intended consequences line-up with the desires of an actor, even if an outside observer were to regard such intentions as negative. In the context of IoT systems, these alternatives are modulated by the technology's agency and its affordances that produce the choices available to the actor. Therefore, while the actor's motive may prompt him or her to park the car in a particular area, the choice that was made (multiplied by many actors) may lead to the unintended consequence of traffic congestion in the area. This unforeseen outcome, the unintended consequence, has resulting effects that can be desirable, undesirable, anticipated or unanticipated from the standpoint of various actors (Morell, 2018: 244). What is undesirable and unanticipated by drivers trapped in a traffic jam may be anticipated and desirable for street vendors who sell refreshments to drivers.

Merton underlines challenges that present themselves when attempting to analyse the nature of intentions, consequences, and the (un-)desirability of an outcome. The knowledge of the situation as well as the possibility for error influence whether an action results in an intended or unintended consequence. It is likely that actions performed in ignorance or by making mistakes (whether through faulty assumptions, interpretations rooted in ambiguity, incorrect design, or an accidental blunder) lead to a higher rate of unintended consequences. The notion of consequence itself is tied to causality and therefore the difficulty in attributing a given consequence to the exclusive outcome of a single action. This is further exacerbated through unintended outcomes that could retroactively be declared as 'intended' – as in the rider who falls off a horse and 'meant' to dismount in this fashion.

The question of 'intention' within innovation must also be viewed from at least two angles: from the vantage point of the <u>innovator</u> who embeds his or her intention in the design and the <u>user</u> who has an expectation as to how a given solution ought to work. This gap is underlined by the statement of the economist Peter Schumpeter, who advocates the innovator's stance by simply defining *"innovation as the setting up of a new production function"* (1939: 84). In contrast, the concept of 'diffusion' features the role of the user by distinguishing mechanisms of innovation adoption alongside degrees of variability, compatibility, non-conformance, and complexity inside social systems (Rogers *et al.*, 2014: 250).

At the starting point of the analysis, therefore, lies the intentionality of the design, i.e., the technical specification of the solution as well as pre-stated goals of other stakeholders such as city planners or administrators. These documented design specifications, user instructions, and other requirements set the baseline for the designed (intended) outcomes of a system as a 'measurement stick' in the comparison to its consequences. The resulting consequences are either intended, meaning desirable and in conformance with the designed baseline, or unintended. The latter can again result in desirable as well as undesirable outcomes across various stakeholders or 'members of the system' that consist of change agents and adopters (Sveiby *et al.*, 2009: 4). The focus of this research are unintended <u>and</u> undesirable consequences that may prompt city planners, administrators, or solution providers to act in offsetting or perhaps preventing unintended and undesirable outcomes.

The categorization of the intentionality of consequences required disciplined data collection and thorough analysis across all stakeholder groups since actors and recipients of actions may disagree on the supposed intention and subsequently differ in their assessment of desirability, undesirability, and expectations of the outcome. An example could be the ambitious city-wide program in Vancouver, British Columbia, Canada to become the greenest city globally (Affolderbach and Schulz, 2017). One component of this plan is the installation of bicycle lanes in the downtown area by repurposing portions of major thoroughfares that have previously been primarily used by automobiles. The effect is an increase in car traffic and a decrease in vehicle throughput, particularly during rush hour. While city administrators may have anticipated this could happen, their goal was to incentivize a shift from cars to bicycles; not all motorists agreed with this intention and viewed the resulting traffic congestion as an undesirable outcome and an unintended consequence.

In addition to conflicting stakeholder agendas, the three dimensions of instrumentation, interconnectedness, and intelligence in a Smart City are interdependent and an imbalance could negatively impact potential benefits and lead to unintended consequences: Even if high instrumentation provides rich data, e.g. through parking sensors that make the system aware of space utilization, but does not flag spaces as unavailable following a street water line rupture (lack of interconnectedness), the value of the information is diminished. Or in a scenario where sensors at an intersection measure traffic throughput (high instrumentation) and these data are used to harmonize traffic lights (high interconnectedness), the full benefit of the system would not be realized if the resulting information is not used for analytical and predictive (intelligent) purposes such as long-term traffic redirection around frequently congested intersections.

As supported by the unfolding data in Chapter 6 (Case Findings and Analysis), there are a multitude of categorical pathways that lead to intended and unintended consequences. In preparation for analysing a manageable set of data, the unit of analysis within Smart City IoT solutions is thus further narrowed to the transportation segment; and within it to automated parking solutions.

1.4 Problem rationale

“For without closed systems there is no reason for the past to resemble the future…” (Archer et al., 2013: 94)

The growing fourth industrial revolution establishes vast data distribution networks as part of the IoT that are connected to highly adaptive systems within the framework of Artificial Intelligence. This transforms previously <u>closed systems</u> into <u>open systems</u>, increases the possibilities for actual usage to deviate from the intended (designed) usage, and gives rise for unintended consequences to emerge as a by-product. These unintended consequences may bear risks for users who interact with this rapidly evolving technology that lies at the intersection of properties of physical objects (machines) and knowledge of human behaviour (Gregor, 2006: 613).

The literature review revealed a gap in a suitable framework to systematically analyse interactions between the entanglements of Human Agency, Material Agency, and Interpretive Schemas. This research develops such a framework that aims to assist creators, implementors, and operators of IoT technologies to think through such risk areas systematically and embed more interactive developmental loops into the design and use processes.

An IoT system provides a unique opportunity to formulate such a framework: The interconnectedness of an IoT network that captures events near-real-time and processes complex analytics for subsequent actionable measures offers ample grounds for the occurrence of unintended consequences.

As outlined in Section 1.2, IoT systems are present in consumer electronics, automotive, environmental, healthcare, robotics, manufacturing, utilities, infrastructure control, and other areas. IoT in the context of a Smart City elevates the technological sophistication and the *open system* concept. Smart City IoT systems sense and model the environment across a wide range of interconnected sensors with large groups of users and massive amounts of data. This complexity further increases the potential for resulting unintended consequences. A Smart City is a fitting environment for this research since applications are widely implemented, there is existing history of data, and a Smart City is more complex than consumer electronics, home systems, manufacturing, etc.

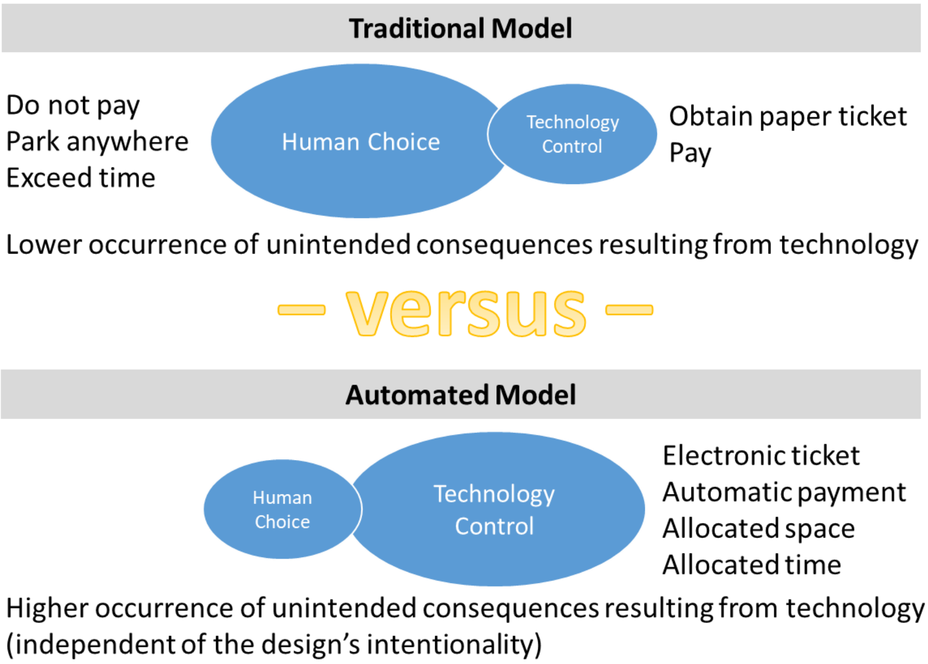
The work specifically examines the design and use of IoT solutions, and the social consequences of such designs, within the transportation realm of a Smart City environment with a further narrowed focus on automated parking solutions. There are three additional considerations for this choice:

First, an existing Smart City as a case study target is a prerequisite when attempting to compare actual with intended usage. In the nascent field of IoT technologies, automated parking solutions are relatively well developed with implementations ranging across cities in North America, Europe, and Asia, where multi-year usage has equipped stakeholders (e.g., users, administrators, solution designers, etc.) with the opportunity to provide content-rich data. These data provided important guidance in the refinement of the proposed Sociotechnical Behavioural Framework (SBF) that was initially developed from the literature review.

Second, the unit of analysis can be contained by examining the approach of designing and using an automated parking solution considering the potential applicability of the proposed SBF. This new framework aims at examining a multitude of human-computer interactions in practice with the purpose to crystallize the routes to intended as well as to unintended consequences. It is important for this to occur in an environment that supplies enough combinations of uses, misuses, design features and flaws, met and unmet expectations, etc. without extending the number of possible situations (and data) beyond a scope that can be accommodated within the confines of this study.

Third, in line with Critical Realist approaches that aim to understand deep non-observable mechanisms, this study adopts a qualitative approach, to explore the interaction between structures and agents in open systems. The qualitative approach is uncommon in the examination of IoT technologies, where extant work is mostly quantitative and numerical in nature and revolves around the technical and economic considerations of IoT applications. Al-Fuqaha *et al.* published a summary of 56 IoT studies conducted between the years 2010 and 2015 that span the challenge areas of architecture, availability, reliability, mobility, performance, management, scalability, interoperability, and security/privacy (2015: 2362). Other researchers, for example Daraio *et al.* (2016), propose a model to derive economic efficiencies in the framework of urban public sector transportation. Here, the researchers focus on the role that social actors play when interacting with such systems. It examines a socio-technical perspective from the vantage point of different stakeholders in this ecosystem (designers, city planners, users, etc.) because no system design can ever fully encompass all use cases. The focus of this study is on adaptive *open systems* in a Smart City IoT setting where a set of elements across structure, function, behaviour, and the environment interact with each other. The qualitative approach lends itself to capturing the unpredictability of human behaviour and the resulting unintended consequences of this behaviour that may not satisfy technical and economic expectations. Based on the existing literature, unintended consequences of human-machine interactions in the framework of IoT/Smart City applications have thus not been sufficiently studied and it is conceivable that these unanticipated consequences have deep and far-reaching impacts. Figure 1.2 outlines the shift from a traditional to an automated model of a parking garage, its corresponding changes in the human choice and technology control balance, and the increase for the potential of unintended consequences:

Figure 1.2 – Example of Shift from Human Choice to Technology Control in a Parking Garage through Automation



In the example of a traditional parking garage without IoT technologies, the potential for human control is more prevalent and deviations by the user from the design (e. g. not paying, not parking in the designated spot, exceeding the purchased parking time) are outside the parameters of what can be controlled by technology. In this case, the user's actions are guided towards the simple tasks of obtaining a parking ticket and paying for it. Conversely, in the example of an automated parking garage with enabled IoT technology, the system design takes on a more prevalent role as the user is 'forced' to interact with the system. In the automated scenario, there are more opportunities for the person's behaviour to differ from the intended design because of the simple fact that increased complexity in automation provides for increased opportunities to diverge from the intended path. Also, it is likely that the technical complexity of such a solution provides more opportunities for the occurrence of unintended consequences that are entirely unforeseen by the designer. The pathways of cause and effect are even harder to trace if, within a technically complex 'black box', the designer had not previously mapped out his or her intention.

This research is directed at examining the intended and realized (whether intended or unintended) impact on human behaviour with the expectation being that there is a divergence between intended and realized (actual) behaviours and actions. Once such differences are identified and understood, the results may point to ideas for better designs, more effective adoption strategies, or other changes to increase a solution's value proposition.

1.5 Parking solutions within Smart Cities: the foundation for a focused exemplar case

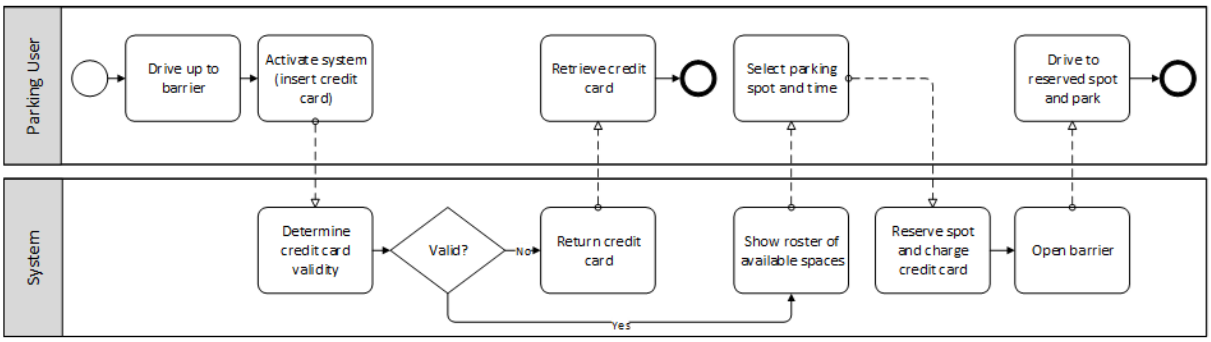
"In the year 2014, US motorists spent 6.9 billion hours, 3.1 billion gallons of fuel, and 160 billion US dollars as a direct result of traffic congestion."
(Schrank et al., 2015)

Smart City IoT technologies are uniquely positioned to reduce congestion and the burden on the environment (pollution) because of their capability to capture millions of individual transactions that are generated within a transportation network and that are spread over thousands of nodes such as sensors or actuators. These technologies are utilized in Smart City transportation solutions for dynamic road lane management to optimize throughput (Boltze and Tuan, 2016), prioritization of emergency vehicles within traffic (Wang *et al.*, 2015: 1), or for better access to (and use of) public transportation (Daraio *et al.*, 2016). One facet of Smart City transportation is automated parking where the availability of parking spaces directly affects the overall traffic situation in urban areas often because drivers are in search of parking spots (Vlahogianni *et al.*, 2016: 192). There are two main groups of IoT-enabled parking solutions:

Intelligent Parking Reservation (IPR) Systems: These are typically used in parking garages and enable users to find a parking space based on preferences. The system allows the person to reserve a stall, park the vehicle without competing for the spot with other drivers, and pay for the service in advance, which avoids queues at the payment terminal or garage exit lane(s). The system is set up either in a closed-loop fashion, where it is not connected to devices within a user's car, or it may be enabled to interact with a vehicle's navigation system and/or a person's mobile device to provide real-time information on overall capacity, fees, and current space availability (Caicedo *et al.*, 2012: 7281).

Figure 1.3 is a simplified process flow diagram of an example of a closed-loop Intelligent Parking Reservation (IPR) System for 'enter and park' activities:

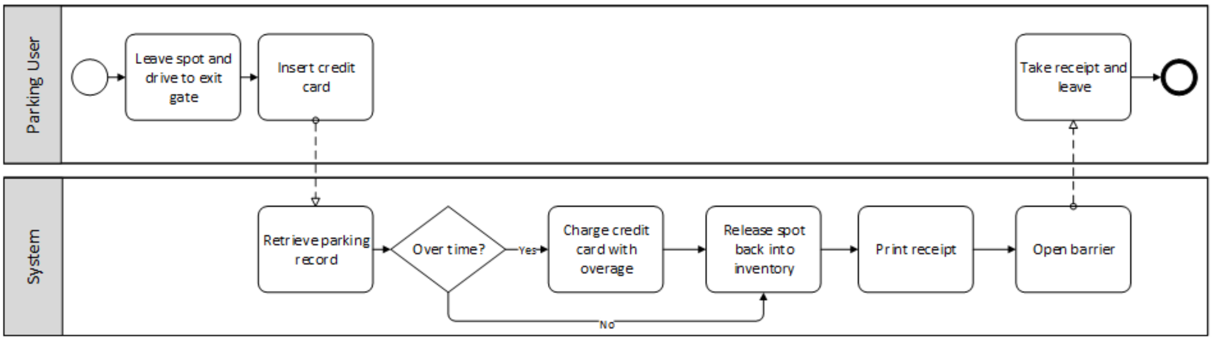
Figure 1.3 – Process Flow for Intelligent Parking Reservation (IPR) System – Enter and Park



In the above process flow, the parking user activates the system by inserting the credit card. The process ends prematurely if the card is found to be invalid. If the card is valid, the system responds with showing a roster of available parking spaces from which the user can choose. After selecting the pre-purchased parking time, the spot is reserved, and the credit card is charged with the appropriate amount. The physical entry barrier opens, and the driver can proceed to the selected parking spot.

Figure 1.4 depicts the simplified process flow for 'leave' activities:

Figure 1.4 – Process Flow for Intelligent Parking Reservation (IPR) System – Leave



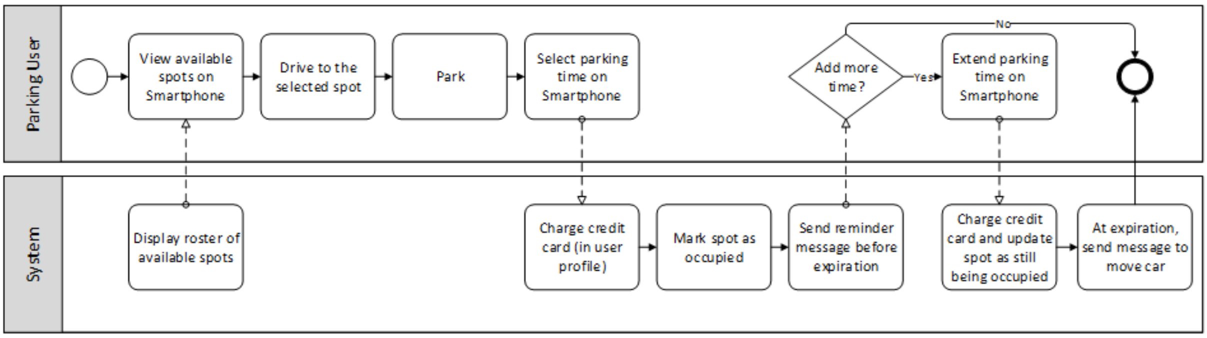
In this flow, the user drives with the car to the exit gate. After inserting the credit card into the reader, the system matches the corresponding parking session via the credit card information that was previously recorded when entering the car park. If the allowed time is exceeded, the credit card is charged with an overage fee. The parking spot is then released back into inventory, the receipt is printed, and the driver is free to leave the facility.

Intelligent Parking Assistant (IPA) Systems: These encompass wireless connectivity and networking, sensor and (potentially) actuator usage, as well as new payment capabilities through mobile devices. An IPA utilizes sensors placed on city streets to track availability and allows users to access a central database via a personal mobile device such as a smartphone. The driver can gauge parking possibilities, pricing, and be guided by the system to the selected spot. The application then removes the chosen parking spot from the available parking space inventory in real-time so that it no longer shows as available to other potential customers. The system also handles all subsequent interactions with the user via the mobile device application such as reminders on parking expiration, extending parking time, payment, etc.

Smart City IoT-enabled parking solutions improve street parking by decreasing the number of occupied spaces in a given area, shifting demand for parking to less crowded surrounding areas, reducing street congestion, minimizing the average walking time for a person from a parked car to the destination, and changing the traffic modal split, meaning the combination of car usage, public transportation, bicycle, walking, etc. (Giuffrè *et al.*, 2012: 17-19). However, in addition to these positive and anticipated effects, one is likely to encounter unexpected human behavioural consequences, of either positive or negative nature, that are experienced by different stakeholder groups, which leads to one cornerstone of this research.

Figure 1.5 is a simplified process flow diagram of an IPA System when parking a car:

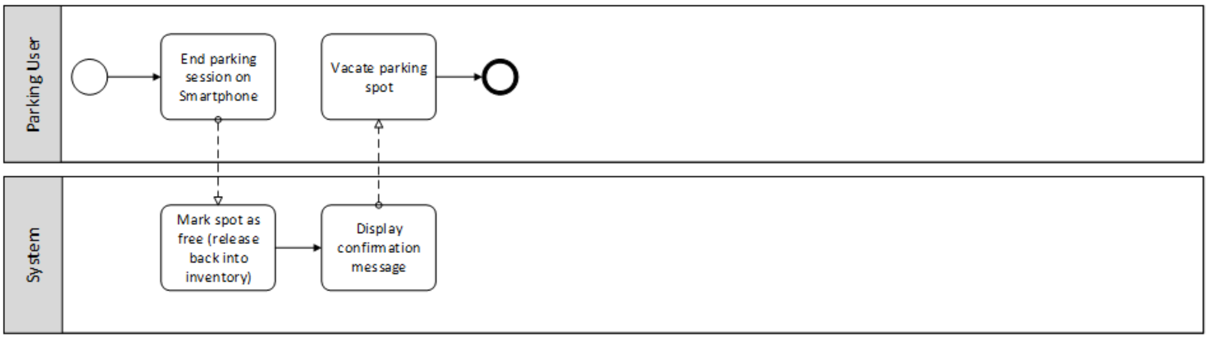
Figure 1.5 – Process Flow for Intelligent Parking Assistant (IPA) System – Park



The user selects the parking spot from a roster of available spaces that are viewable on the smartphone. After parking the car, the credit card in the user profile is charged based on the selected parking time. The parking spot is then marked as 'occupied' by the system in a database. The system sends a reminder to the user's smartphone (via a text message) shortly before the allowed parking time is reached. If the user elects to add more time, the credit card is charged again, and the parking spot database is updated with the extended time occupation of the space. Once the parking time expired, the system sends another text message to the user with the alert that the spot must now be vacated.

Figure 1.6 shows the steps that occur when the user leaves the IPA System:

Figure 1.6 - Process Flow for Intelligent Parking Assistant (IPA) System – Leave



After ending the parking session on the smartphone, the system releases the occupied parking spot so that it shows as 'available' for other users. The driver then vacates the parking spot.

These solutions differ significantly in their physical layout and complexity. The following Table 1.1 compares the IPR and IPA systems across several key dimensions:

Table 1.1 – Comparison between IPR and IPA Systems		
Dimension	**IPR System**	**IPA System**
Physical space	Parking garage	Street parking
Access and security	Controlled via entry and exit barriers	Open (on the street)
Technical complexity	Medium – system keeps availability of individual spots	High – multitude of IoT sensors on streets that send availability and non-availability signals
User setup	Simple – only need credit card for the duration of the transaction	Complex – need to create user profile with payment information
Interaction between user and system	Limited – only at entry and exit points	Frequent – for user profile setup, space selection, parking activation, time reminders, extensions, and session closure
Data security risk	Low (if system does not permanently store credit card numbers)	High – system breach could expose credit card data and (private) parking location history with dates and times

IPA systems exhibit higher technical sophistication and more frequent and complex user/system interaction than an IPR system. The choice for this study is an IPA system with the potential to lead to higher occurrences of unintended consequences.

1.6 Research questions, mapping to chapters, contributions

"It is not what we have thought, but rather how we have thought it, that we consider to be our contribution to theory." – Carl von Clausewitz (Stoker, 2014: 286)

The current lack of research on IoT technologies and unintended consequences, backed up by the literature review in Chapter 2, suggests the following research questions:

i. *What are the unintended consequences and their evidence based on intent and design versus use?*

The first question (above) is explored in **Chapter 2** (Literature review) to develop a framework from well-established and relevant theories and further expanded upon in **Chapter 6** (Case findings and analysis).

ii. *What are the potential generative mechanisms behind unintended consequences and how can we model them?*

The starting point for the question above lies initially in **Chapter 4** (The Sociotechnical Behavioural Framework in thought experiments). In line with the abductive approach, the chapter explores more systemically what Sætre and Van de Ven (2021) refer to as “evaluating a hunch”. The thought experiments are therefore an early assessment of the Sociotechnical Behavioural Framework. The question is ultimately answered in **Chapter 6** (Case findings and analysis).

iii. *What is the intended impact of using an IoT car parking solution within the context of a Smart City?*

The answer to the third research question above is provided in **Chapter 5** (Case description). The analysis of why a specific design or intent led to unintended consequences occurs in **Chapter 6** (Case findings and analysis). In referencing back to **Chapter 4** (The Sociotechnical Behavioural Framework in thought experiments), the attempted explanation of the generative mechanism (‘why’) occurs by utilizing the SBF.

iv. *What suggested actions could minimize unintended consequences and improve the design and interaction with IoT Smart City technologies?*

The last question (above) is addressed in **Chapter 7** (Discussion). The study can then be summarized as:

What human technology interactions generate routes to unintended consequences in IoT parking systems within Smart Cities?

In answering these questions, the research is expected to contribute the following to theory and practice by filling a set of identified knowledge gaps as well as by suggesting a new approach to current theoretical divides (Alvesson and Sandberg, 2011: 250-251):

First, <u>progress theoretical development</u> through the creation of a framework to systematically analyse interactions between humans, technology, and modulating interpretive schemas with the aim to assist creators, implementors, and operators of IoT technologies to think through risk areas systematically and embed more interactive developmental loops into the design and use processes. This is accomplished through the creation of a Sociotechnical Behavioural Framework (SBF) that abductively infers the mechanisms causing unintended consequences by examining the paths to events that arise through the systematic interaction between the three sociotechnical domains of Material Agency, Human Agency, and Interpretive Schemas. The SBF is laid out in a Venn diagram where each sociotechnical domain is depicted by a circle with interconnections and with all three circles overlapping at the centre. This central three-way intersection represents an emergent property beyond purely technological effects. The powers and tendencies of the three domains of human and technology interaction produce the deep constitutive entanglement that is described in the theory of Sociomateriality (Orlikowski and Scott, 2008). As a first step, the framework analyses the sequence of interaction loops of designed and intended pathways between the three sociotechnical domains. In a second step, the work draws upon Affordance Theory and Analytical Dualism (Archer, 2010) to separate, temporally and analytically, the contribution of individual components to the recursive relationship between the practice of Material Agency, Human Agency, and Interpretive Schemas. By modelling the variations between expected and actual inputs, it becomes possible to identify the unexpected outputs and unintended consequences that arise from the interplay of the three domains. The framework can be used to analyse actual recorded examples of unintended consequences and to potentially predict future problems. It advances relevant theory by connecting the underlying roots of Sociomateriality (Orlikowski, 2000) with Affordance Theory (Gibson, 2014) and Analytical Dualism (Archer, 2010) as a route to understanding morphogenesis (i.e., the way a system changes) over time.

Second, the <u>retroductive testing</u> of the abductive framework that is in line with Critical Realism's onto-epistemology. This provides practical learnings and improvement suggestions through a case study using data from an actual IoT-based car parking system within the Smart City of Santander, Spain. Data collected from system designers, operators, city officials, and parking system users facilitated the identification of expected outcomes through process flow charts. The comparison between intentions and observations resulted in the identification of 30 routes leading to unintended consequences. These were classified and studied using the SBF to identify their properties, and through reasoning for their occurrence, allowed the suggestion of their generative mechanisms. Testing the framework in this way adds to the knowledge of the sociotechnical design and suggests improvement opportunities in <u>comparable contexts</u>. The newness of the technology, its actual availability in cities, time, and complexity, limited this exploratory case study to one detailed example. The transferability question of the single case study is strengthened in two ways: by utilizing input from actual users of the technology to understand the generative mechanisms in more depth, and through a thought experiment that is included in the thesis.

Third, the application of findings as a series of recommendations and a potential methodology to identify how the new framework could be used in praxis to limit the occurrence of unintended consequences in sociomaterial systems and/or to analyse their causality and hence improve IoT and related systems design in a similar Smart City context.

The literature review illuminates the existing building blocks within the extant literature that have contributed to the development of the SBF. The framework attempts to disentangle the intertwined relationships between humans, technology, and interpretive schema (norms, rules, laws, designs, and standards). It proposes a pathway towards examining these interdependencies with the aim to explore underlying unintended consequences. It also attempts to offer insights into their likely causes and suggests, within the confines of a case study, potential design improvement ideas that could harmonize future usage of IoT Smart City technologies with the intentions of their creators and administrators.

1.7 Thesis summary

“Good research is more like a poem than a novel.” (Daft, 1983: 541)

This thesis consists of eight chapters that are arranged as follows:

Chapter 1 introduces this summary and provides general background information that may be helpful in contemplating the research questions. This starts with the context of the problem in the transformation of cities into technology-enabled Smart Cities. It is then complemented with the contribution and challenges of IoT technologies and the problem of diagnosing intended and unintended consequences. The chapter provides the foundation for a focused exemplar case of parking and provides the rationale for the investigation of the problem in practice. It then closes with the introduction of the research question and its sub-questions.

Chapter 2 encompasses the literature review. This work’s main theoretical contribution is the Sociotechnical Behavioural Framework (SBF) that integrates several existing theories, which originated in the social realm and more recently branched into technology. These theories were previously not combined, and the chapter maps these interrelationships. It also covers technological and social determinism, merges the technical with the social, and introduces the SBF with the goal to highlight how underlying tributary theories are incorporated in the framework. These main theories are: Affordance Theory (Gibson, 2014), Structure and Duality (Giddens, 1984: 17-19), Structurational Model of Technology (Orlikowski, 1992: 410), Sociomateriality (Orlikowski, 2000) with its explanation of a constitutive entanglement (Orlikowski and Scott, 2008), as well as Analytical Dualism and morphogenesis (Archer, 2010).

Chapter 3 describes the research methodology and design by reasoning the choice of ontology and epistemology among the broadly available paradigms. It states the case for selecting Critical Realism (CR) as a *"compelling third way between the poles of positivism and interpretivism"* (Sayer, 1999: 2-3). It then argues the fit of CR for this study based on its stratified ontology that distinguishes between the *real*, the *actual*, and the *empirical* to overcome the epistemic constraints of both positivism and inductive empiricism through abduction and retroduction. CR links observable effects with empirical findings and higher-level structures, mechanisms, and powers, leading to the suggestion of causal inferences and possible generative mechanisms. This is helpful when attempting to improve Smart City IoT applications in the future. The chapter then overlays CR with Sociomateriality and Analytical Dualism and continues with the description of the selection process for a retroductive (single / embedded) case study. It is based on a combination of Yin and Eisenhardt to transpose existing theories into a new approach within a different context (Eisenhardt and Graebner, 2007: 26).

Chapter 4 explains the SBF in detail as a graphic that is laid out as a Venn diagram with three overlapping circles that represent sociotechnical domains: Human Agency, Material Agency, and Interpretive Schema. The framework abductively infers unintended consequences as events that can be modelled by showing the systematic interaction between the three domains. The framework is then applied to three simulated thoughts experiments: a technology-enabled car park, an existing case study (Eaton *et al.*, 2015), and a manual car park to trace systematic occurrences through the framework's pathways. These 'dry runs' improve confidence in the framework by providing triangulation opportunities with the single case study.

Chapter 5 describes the object of the empirical case study: the city of Santander in Cantabria, Spain. The chapter outlines this Smart City's strategy, goals, and timelines as an early adopter of IoT technologies. It then draws the focus to Santander's Smart Parking solution that forms the basis of this case study.

Chapter 6 contains the findings and analysis of unintended consequences derived via the SBF. It further explores the results by displaying the output of the SBF in a Context–Mechanism–Outcome (C-M-O) table (Pawson and Tilley, 1997) and describes unintended consequences in a time-phased morphogenetic view (Archer, 2010: 238). This highlights, where possible, the individual components that form the recursive relationship between the practice of Human Agency, Material Agency, and Interpretive Schema. The work then provides a possible reasoning for their occurrence, allowing the suggestion of generative mechanisms.

Chapter 7 discusses the findings of this thesis at a higher level of abstraction by linking individual elements back to the research methodology. It makes the case as to why Critical Realism and Analytical Dualism are fitting complements to Sociomateriality and demonstrates the usage of the Sociotechnical Behavioural Framework. It then transposes the findings into transferable general Smart City improvement opportunities.

Chapter 8, the conclusion, summarizes the answers to the main research question and sub-questions, reiterates the contributions of the thesis, and closes out the work.

The next chapter addresses the problem through a review of the relevant literature.

2 Literature Review

"The map is not the territory…" (Korzybski, 1951)

There are many models that have been developed and applied over the years to advance the understanding of the relationship between material objects (technology) and human actors (society). One early and dominant area of research in the 1980s was the linking of computer user interfaces with human activities (Bodker, 1989) that resulted in an in-depth study of activity theory (Engeström, 1990). Over the past 30 years, the discourse between the degree of separation (or fusion) of the technical and the social has oscillated between two discrete ontological priorities: technological determinism and social determinism, with the former maintaining technology as the starting point in influencing the social and the latter arguing the reverse. One fundamental component in perceiving the meaning of the relationship between the technical and the social is to gain an understanding of our underlying views and assumptions. This includes their relevancy to the development or application of a model and their contribution to identify, articulate, and challenge the advancement of interesting theory (Alvesson and Sandberg, 2011: 254).

As subsequently expanded on in this chapter, other theories attempt to amalgamate these two distinct views, but in so doing make it hard to disentangle the patterns of technological-societal interaction that may cause unintended consequences. This leads to the introduction of a Sociotechnical Behavioural Framework that accepts the blend between the material and the human while offering an alternate path to probe the connections between the theoretical tributaries.

2.1 Technological and Social Determinism

"All human knowledge is a social artifact…" (Habermas, 2015: 347)

<u>Technological Determinism</u> rests on the argument that technology has a defined character that shapes the form of an organization and society at large – going as far back as Karl Marx's maxim of *"the steam-mill gives you society with the industrial capitalist"* (2008). At this far end of the ideological spectrum lies 'objectivity' with the one-directional mediation of technological artifacts on societal responses – and, if there was ever a counter-flow response, the social effect would only occur during construction of such an artifact and prior to the point of stabilization where general consensus is reached on what the technology can do (Woolgar and Grint, 1991: 370). Technological Determinism can be seen as a consistent way of describing the development of any system over any finite period of time (Bhaskar, 2013a: 61)

and has a long history of putting systems in contrast with their effects on processes and organizations (Woodward, 1958). It argues that technology substitutes mechanical equipment for human labour (Blau *et al.*, 1976: 21) and claims that independent variables (i.e. technologies) affect the dependent variable of a work organization (Perrow, 1967). At an individual level, the one-sided relationship between human and machine is parallel to the Cartesian separation of mind and body (Yoo, 2010: 218) and underlines the separation of technology as something separate from tasks and users as a mere abstract representation of reality (Orlikowski and Scott, 2008: 439).

In contrast, <u>Social Determinism</u> imbues the notion that technology bears little importance for social integration and that *“wider cultural and social structural patterns of specific societies determine the way in which technology is used”* (Barnes, 1974: 102). Over time, computers have become evocative objects, provoking self-reflection and taking on many shapes and meanings as with a ‘Rorschach-inkblot-like’ medium of projection (Turkle, 2005: 17, 21, 35). These projections or interpretations, in turn, influence people’s responses in their interaction with technology (Prasad, 1993: 1402). One recent phenomenon is the near universal expectation that every computer monitor is a touch screen, and that swiping functionality would be enabled everywhere. Social Determinism assigns dynamic possibilities to human agency as a composition of variable and changing orientations over time (Boudreau and Robey, 2005: 4).

The rift between Technological and Social Determinism is wide where much of information systems research throughout the 1970s and 1980s tilted towards one or the other. Yet neither, when treated with mutual exclusivity, provides for a holistic description of the technology-human actor relationship (Orlikowski and Robey, 1991: 143-145) – since *“work organizations are not solely technical or rational systems designed to accomplish managerial goals, but they also embed natural or social systems whose characteristics extend beyond the rational and thus connect them with all other human social groups”* (Rouse and Baba, 2006: 70). If technology (artifacts, techniques, systems, media) and the social (meaning, activities, contexts, outcomes) remain on either side of the divide, the outcome would likely be a conceptual and/or methodological predisposition in their possible findings (Orlikowski and Scott, 2008: 463).

2.2 Merging of the technical and the social

“When everything is inseparable, the same, and one…” (Author)

An attempt to reconcile these pronounced polarities lies in looking at human and material agency in a reciprocal, temporally emergent, dialectic of resistance and accommodation

(Pickering, 1993: 567, 576). An example of this is the social construction (and reconstruction) of the bicycle towards the end of the 19th century. Prior to that, bicycles were high wheeled in front, unstable, difficult to get on and off, and causing the rider to fatigue easily since propulsion and steering were combined in the front wheel. These vehicles were more useful as 'toys' for aristocratic young men to impress their lady-friends rather than constituting a practical mode of transportation. In overcoming the initial human resistance, other relevant social groups started using the bicycle, for example ladies in dresses, elderly men, or sport and tourist cyclists in an act of human accommodation. The design then transformed over the course of approximately 50 years (material accommodation) to the current safety bicycle with a cross frame, equal tire sizes, and a chain-based transmission of power to the rear wheel (Bijker, 1997: 53-100).

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In moving the debate about whether technology determines the social or the social determines technology to a different playing field, several researchers pivoted from a substantialist to a relational ontology: The former argues that human and material agency (i.e. people and things) exist as separate and self-contained entities that interact and affect each other (Cecez-Kecmanovic *et al.*, 2014: 809); the latter cements the ontological inseparability of human and non-human agencies (subjects, objects, bodies, and the environment). These two agencies are intra-actively co-constituted, much like in M.C. Escher's "Drawing Hands" where one hand (human agency) is simultaneously the creator as well as the creation of the other hand (non-human agency) in what Barad (2007: 170) and Schrader (2010: 283) summarized as Agential Realism.

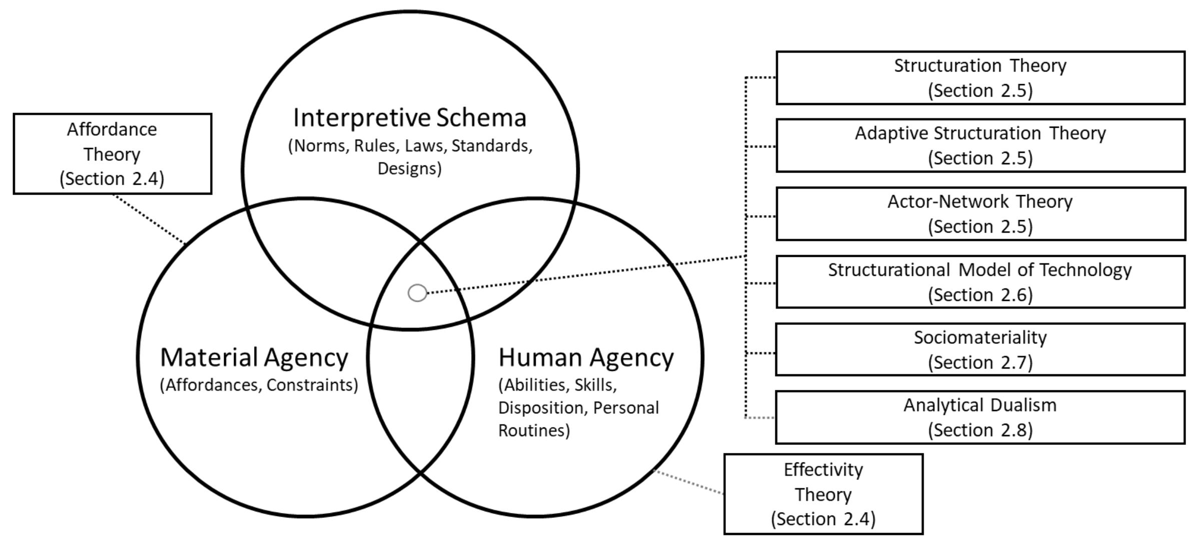
Orlikowski and Scott (2008: 434, 454) capture this inseparability between the technical and the social in their meta-theory of Sociomateriality that posits that technology, work, and organizations cannot be conceptualized separately and are essentially fused together as mutually co-constituting elements in a persistent duality. The theoretical framework abandons the belief that structures, i.e. rules and resources, shape action unidirectionally by facilitating or constraining certain outcomes (Orlikowski and Robey, 1991: 148) and that they are embodied within technology (Orlikowski, 1992: 410) and (DeSanctis and Poole, 1994: 125). Sociomateriality advocates the entangled, unpredictable, and unstable union of the material (technological), human, and normative (structural/interpretive) manifestations of the world that subsequently results in the complete fusion of all three (Orlikowski, 2000: 406).

2.3 Early introduction of the Sociotechnical Behavioural Framework

"Whenever we construct a model, we commit an act of wilful ignorance."
(Weisberg, 2014: 226)

The synthesis between Material Agency (affordances, constraints) of technology, Human Agency (abilities, skills, disposition, personal routines), and Interpretive Schema (norms, rules, laws, designs, standards) are expressed in Figure 2.1 with three intersecting circles of a Venn diagram. This Sociotechnical Behavioural Framework represents a substantive part of this thesis and is described in detail in Chapter 4. In this section, the early introduction of the basic framework is merely meant to highlight how contributing theories and concepts relate to each circle.

Figure 2.1 – Foundational Theories and Precursory Models for the Development of the Sociotechnical Behavioural Framework



The framework depicts the three-ring central intersection as the manifestation of Agential Realism and Sociomateriality where Material Agency, Human Agency, and Interpretive Schema are constitutively entangled.

Gibson's (2014) <u>Affordance Theory</u> describes the material capabilities of an object combined with how an agent perceives its usage (Material Agency) – whereby an 'agent' is defined as anything that is capable of bringing about a change in something, including itself (Bhaskar, 2013a: 99). Gidden's (1984) <u>Structuration Theory</u> adds the elements of Human Agency (abilities, skills, disposition, and personal routines of an individual) to the surrounding social structure of formal and informal rules that build a duality between the material and the human sides, which DeSanctis and Poole (1994) complemented with <u>Adaptive Structuration Theory</u> –

the recognition that an object's capabilities extend from sole material affordances to expectations of the designer and the surrounding ecosystem of what objects are intended to do.

These theories will be described in-depth in subsequent sections of this chapter – for now, their meaning can be illuminated by the example of a car: Its Material Agency enables transportation; a driver perceives various ways for its utilization based on actions and outcomes that the technology affords (Affordance Theory). He or she must be physically able to operate the controls of the vehicle, possess the skill of driving, decide to drive rather than to walk, and adhere to rules (Structuration Theory). These rules extend across the car's design, formal licensing, and traffic rules, as well as other customary (informal) rules, that if not followed, would lead to consequences for the driver. The affordance of a car is more than merely transportation as evidenced by the myriad of automobile brands, models, and feature sets – the distinctions between sports cars, utility vehicles, luxury sedans, electric cars, driverless vehicles, etc. cater to different lifestyles, needs, and expectations of drivers (Adaptive Structuration Theory).

Early works on participative design stressed the importance of examining both social and technical aspects in IT research by spreading awareness that *"treating people as adjuncts to machines does not work"* (Mumford, 1983: 47) and that enabling users and technical experts to be designers (functionality owners) vastly improves adoption and value creation of technology (Mumford, 1983: 47-57). The ubiquitous spread of technology as a manifestation of material objects has underlined the importance, and also the absence, of innovative conceptual lenses to examine the influence of technologies on organizing realities (Orlikowski and Scott, 2008: 436) whereby technology is a dynamic, distributed, and interdependent equivoque that leaves us with several plausible interpretations (Weick, 1990: 1). The accelerating lifecycle of technological applications is generating an ever-increasing number of random networks between man, machine, and organization that become inextricably fused (van Lier, 2013: 73). Actor-Network Theory attempts to bond the formerly independent workstreams of human and non-human elements with an orientation towards the creation and maintenance of coextensive networks (Walsham, 1997: 466-467). These networks, consisting of people, organizations, software, computer and communication hardware, and infrastructure standards can be analysed within the same theoretical framework that further examines the intertwined relationships between humans, technology, and rules in the Structurational Model of Technology (Orlikowski, 1992: 410).

In the example of a car, this amalgamated relationship is expressed in that a car is designed by humans, that technological advancements (safety features, driver-assistance or driverless capabilities, fuel efficiencies, etc.) influence how humans use a car, that the usage 'reverberates' back onto future design modifications, while new rules are introduced (design, safety, and emission standards, etc.) that then structure in turn how the technology is to be used by humans. The Structurational Model of Technology was replaced by the meta-theory of Sociomateriality, which accorded far more weight to Material Agency. Sociomateriality advocates the dissolution of boundaries and complete assimilation between the triad of humans, technology, and rules (Orlikowski and Scott, 2008: 434, 454).

We know that the usage, design, and regulatory framework around cars is constantly evolving with Sociomateriality taking the stance that there is no distinction between the contributing roles of humans, technology, and rules. This may form a parsimoniously organized and clearly communicated framework, a cornerstone to a coherent theory (Bacharach, 1989: 496), but suggesting previously unsuspected relationships and connections that change actions and perspectives (Weick, 1989: 524) proves difficult when faced with an 'emergent property monolith'.

The possibility exists to examine such a 'monolith' by analytically distinguishing between the structuration perspective and a morphogenetic view: The former espouses the inherent duality of structure where social structure shapes, and is recursively and elusively shaped by, social interaction (Giddens, 1979). The latter is ontologically consistent with the former while epistemologically using a form of Analytical Dualism to examine how processes elaborate or change a system's given form, structure, or state over time.

The perceived dichotomy between the two viewpoints is grounded in the role of temporality and flow in dynamic processes (Langley *et al.*, 2013: 4). While sociomaterial dualities consist of emergent properties in an amalgamation of contributions from humans, technology, and rules – in taking an extended process view, their individual contribution could be recognized as an emergent turning point affecting the system, and therefore the next time-phased instantiation (cycle) of system adaptation. The dimension of time is especially important when considering that unintended consequences are often seen as 'fires' that occur unexpectedly (Morell, 2018: 243).

The Sociotechnical Behavioural Framework combines and elaborates on several established theories while applying them in a fashion that accounts for the dynamically changing technology environment of IoT technologies. The following theories and precursory perspectives form the integrated building blocks for the construction of the framework.

2.4 Theories and precursory perspectives: Affordance

"A hammer cannot fly, and a balloon does not drive a nail into the wall…"

(Author)

Gibson (2014: 127-139), leaning on the ecological interaction between animals and objects and the psychology of perception, established how people and animals orient to objects in their world ("environmental niche") in terms of possibilities or potential for action and physical enablement that such objects afford.

These affordances can be different for different species and human affordances (effectivities) complement what humans are able to do with an object or artefact. Humans may alter the environment to change affordances by making beneficial ones more available and limiting unprofitable ones. These affordances are equally a fact of the environment as well as a fact of behaviour – they are real, objective, neutral, and devoid of value and meaning. The object of a hammer can be used to drive a nail into the wall as well as to inflict injury on a person; yet, what a hammer affords, i.e., its material agency, value, or utility does not change with an observer's changing needs.

Gibson's theory of affordances remains neutral in the debate whether an object's functional aspects determine its usage or whether social influences drive an object's capability (Grint and Woolgar, 1997: 21). Affordance Theory thereby adheres to the rules of scientific determinism where the object features a certain size, weight, shape, etc. and the user's ability determines its usage. It does not subscribe to two prominent psychological theories that are linked to perception: *Gestalt*, where Koffka (1935: 345) argued that the utility of a mailbox increases with a person wanting to mail a letter; and *Cognitive Psychology*, where the brain plays an intermediary role in attaching value to what it perceives. In the Gibsonian account of affordances, the ability of a mailbox to hold mail is not influenced by a person standing in front of it with a letter nor is the edibility of a food item related to the observer's degree of hunger. It steers clear of the opposing ends of a spectrum that comprises realism/determinism, where inherent properties of worldly objects act as constraints, and constructivism, where the *reality* of objects is an outcome of a discursive relationship between a person and the object.

Even though Material Agency exists independently of people in the Gibsonian view, affordances contain functional (objective) and relational (subjective) aspects whereby the latter frames relationships between people and the materiality of things with which they come in contact. Affordances, therefore, occupy a regulatory role in the space of enactment (Niemimaa, 2016: 52). In this context, functional aspects (objective affordances) relate to what the *"thing itself"* is capable or not capable of doing – a hammer is able to amplify force or weigh down another object. The physical qualities or natural properties of the item's objective affordances are stable – transformation forces are balanced, spatial positioning is fixed, and other attributes (e. g. chemical composition, dimensions, etc.) are unchanging in a stable passive equilibrium (Michell, 2012: 107-108). Relational aspects (subjective affordances) refer to how an agent perceives using the properties of an object to act within the confines of the agent's capabilities or to achieve a goal (Ortmann and Kuhn, 2010) which is in turn driven by the ability, experience, disposition, motivations, or circumstances of the agent (Greeno, 1994: 338). One needs to be able to grasp a hammer, swing it with sufficient strength, hit the nail on the head for it to enter the wall, and start out with the objective to accomplish this (Hutchby, 2001: 448). The hammer and the user's intention to operate it in a certain way fuse material and human agency in what Stoffregen sees as an emergent property (2003: 124) and in what Karen Barad refers to as a sociomaterial assemblage (2007).

The link between functional aspects (objective affordances) and relational aspects (subjective affordances) is fundamental for there to even be an affordance – the two components must come together for an object to have the capability to transform or to be transformed (Heft, 2003: 154) and to subsequently create value for the user (Weigand *et al.*, 2006: 322-323). Affordances typically exist as a collection of pairs that contain either artifact-to-artifact affordances, connecting two individual passive objective affordances, such as a hammer's handle with its metal head, or artifact-to-user affordances, linking a passive objective affordance with a driving resource; for example, the hammer's handle and the user's hand with the goal to use its amplification of strength (Maier and Fadel, 2006: 15). Ultimately, a passive object affordance coupled with the active agent resource is necessary to achieve a transformative goal (Montesano *et al.*, 2007: 1). On one hand, the object affordance (materiality) favours, shapes, invites, and constrains how it is used (Zammuto *et al.*, 2007: 752). On the other hand, the transformative goal of using the affordance of a charcoal pencil and paper to create a drawing heavily depends on whether an artist or an untrained human attempts the endeavour (Faraj and Azad, 2012: 253).

Norman (1988) first extended Gibson's theory of affordances into the realm of Information Technology by describing how perceived affordances facilitate how an object, or technology, is used by a person (Norman, 1999). The increased permeation of digital technology rapidly expands the possibilities of (perceived) affordances and capabilities across products, services, and operations. It allows designers of solutions to entangle physical objects with software-based digital capabilities that are editable, interactive, open or reprogrammable, and distributed (Kallinikos *et al.*, 2010). Where 20 years ago, city buses had the simple capability of transporting passengers between stops, drivers now receive valuable information (e.g., road closures, traffic delays, etc.) that enable them to quickly change routes. Simultaneously, tracking the GPS coordinates of a bus, coupled with traffic data, allows for the recalculation of anticipated arrival times at upcoming bus stops. This information feeds back into the system so that the downstream public transportation network can dynamically adjust dependent departure times and routes; in addition to passengers being kept up to date regarding schedule modifications.

The pervasiveness of digital technologies gives rise to two prevalent characteristics (Yoo *et al.*, 2012): Convergence – in that a city bus transitions into a wirelessly connected motor vehicle, a bus driver becomes (to some degree) a computer operator, and the bus manufacturer partially assumes the role of a technology provider. Generativity – where unprompted change is engendered by large, varied, and uncoordinated audiences (Zittrain, 2006: 1980) – leads to inherently dynamic and malleable digital technologies and derivative innovations in new layers of affordances (Yoo *et al.*, 2012) that are recursive in nature as well as scalable and flexible (Tilson *et al.*, 2010: 5). In the example of connected city transportation vehicles, this may manifest itself in the public, commercial, or academic value of *Big Data* that is generated by the transportation network in that it could be used for future route planning, advertising, behavioural research, and other applications.

Affordance Theory is a vital tributary to the Sociotechnical Behavioural Framework in that it provides a perceptive lens on Material Agency as a description of the value of its utility. Affordances made available through technology are a promising way to analyse the technology appropriation process (Faraj and Azad, 2012: 12) whereby this process accounts for the fact that objects (generally) do not act on their own. The dimension of human agency, as an expression of human social behaviours prompted by the abilities, skills, disposition, personal routines, and the value framework of an individual, is in a recursive relationship with the material world. This feedback cycle, and its benefit to diagnose problems, was expressed by Volkoff and Strong (2013: 823, 831) in that 1) affordances bear the potential for action rather than the action itself, 2) they contain a relational aspect, 3) they connect to an immediate concrete outcome resulting from goal-directed behaviours, 4) they are applied at multiple levels.

Affordance Theory alone would neglect the interactions that realize the potential through action at multiple levels. This leads us to the next section that explores the issue of structure and duality.

2.5 Theories and precursory perspectives: Structure and duality

"The whole is stored in all the parts." (Morgan and Smircich, 1980: 495-496)

Material agency (affordances, constraints) and human agency (effectivities) are in life constantly interacting with the social practice (rules, relations, duties, habits, expectations, etc.) in which they occur. Over time, several researchers elaborated upon the degree of this interaction and increasingly fused the material, human, and social: Pickering (1993: 559) likened the intertwined and temporally emergent dialectic of resistance and accommodation between the material and the human to a mangle – the mechanical appliance with two rollers that wrings water out of wet laundry. Latour (2005) added the symmetrical position in Actor-Network Theory that elevates non-human actors in an equal engagement in reassembling the social and Suchman (2007) advocated that material objects are inextricably entangled with the social practice in which they are used. This goes beyond the mere application of social rules in that its systemic form is socially-analytically formed by loosely bound time-space social systems (Giddens, 1984: 17) that pass from one actor to another while being shaped and reshaped in the process (Bijker and Law, 1992: 8) in an ongoing reconfiguration of the world (Barad, 2003: 818).

At the heart of these viewpoints lies the rejection of the Cartesian view on dualism that is expressed in the contrast between mind, body or agency, and structure. One foundational building block in understanding materiality in the production of social life is Structuration Theory, which looks at how human actors structure their environment so that Material Agency works for them. Giddens (1984: 8) equated it with a *"capacity for action in the durée of day-to-day life as a flow of intentional or unintentional activities, with intended and unintended consequences, that systematically feedback to be the unacknowledged conditions of further acts".*

The iterative relationship between human agency and social structure, the Duality of Structure (Giddens, 1984: 19), suggests that all human actors acquire and retain knowledge, either discursively (by what is reasoned or argued) or practically (by what is tacitly 'being done'), and possess reflexivity in observing and understanding their actions. This interaction is bound by the situated nature of action, the difficulty in articulating tacit knowledge, unconscious sources of motivation, and unintended consequences of action (Giddens, 1979: 144). The inherent perpetual feedback loop ties human activities to institutionalized norms, rules, laws, standards, designs, and expectations (social structure) where these in turn adjust people's values, abilities, and skills (human agency) through authoritative (extending over persons or actors) and allocative (extending over objects, goods, or material phenomena) power in organizational Structures of Domination (Giddens, 1979: 92-93) and (Giddens, 1984: 27).

Gidden's Structuration Theory is to be seen as a social meta-theory and as a view on the world rather than a concrete research program (Weaver and Gioia, 1994) where Giddens himself stated that his theory does not lend itself to empirically test for explanations of social behaviour (1983: 77). This led several researchers to stake out pathways for the theory's application in the realm of technology and to connect the concept of Duality of Structure to a more refined definition of Material Agency in the context of technology – by breaking down the latter into three main properties:

Time – the transcendence of time (continuance) where material objects are present and unchanged (at least in their <u>current</u> instantiation or version) during their lifespan – from the moment of formation to the moment of extinction in an endurance that is in contrast to events that can occur at different points in time or properties as attributes or qualities of objects (Faulkner and Runde, 2010: 3).

Space – materiality encompasses the idea that an object's properties transcend space, where it makes no difference where they are used, as expressed through spatial attributes such as location, shape, volume, and mass. With this, an object can only be in one place at one moment in time (Leonardi, 2012: 18).

Structure – a material object embodies structure in that its parts are organized in a distinct way where these parts could represent component objects, including a divergent time-continuum that can apply to individual components as opposed to a group or system of parts.

For example, an airplane is on a time-continuant from its first to its last flight, transcends space in that it exists only where it 'is', and has its parts structured in a way that will enable it to fly. However, during the lifespan of an airplane, tires, engines, doors, or even parts of the fuselage may be replaced. Material structures can be subdivided into physical and logical (non-material) objects with examples of these being computer programs, web pages, digitized images, videos, etc., as well as intellectual property-related objects such as designs, mathematical algorithms, musical/literary compositions, or other documents (Leonardi, 2012). Even though such non-material objects are absent spatial attributes, they do depend on a vehicle ('bearer') as a prerequisite for their physical manifestation to be stored, accessed, transferred, and communicated (Faulkner and Runde, 2010) and can by extension be seen as enactments of material structure (Lucas, 2011: 116).

These objects can be nested as in the example of an instruction manual (non-material object), that is contained in a Word document (non-material object) and stored on a computer hard disk (material object). The property of material structure can be further split into 'hard' and 'soft' components under the banner of Adaptive Structuration Theory – where 'hard' implies structural features of technology in a Gibsonian's sense of Material Agency, i.e., what does the technology afford the user to do? and 'soft' entails the spirit of the feature set as in the general intent regarding values and goals underlying a given set of affordances. The featural spirit set is not solely the intent of the designer, nor simply the expectation of the user, but rather the combination of a variety of factors: the underlying system design metaphor, the incorporated features and how they are named/presented, the nature of the user interface, the training/guidance material, and available training/help in the usage of the system (DeSanctis and Poole, 1994: 125-126).

Both, structural features as well as the spirit of the feature set, lead to differing appropriations of technology analogous to Gidden's authoritative and allocative structures of domination (Poole, 1990). These appropriations can occur either faithfully/as expected or unfaithfully/unexpected (DeSanctis and Poole, 1994: 129-130) whereby the latter could further be subdivided into errors (misperception, lack of understanding, and slippage) and intentional unfaithful usage, such as sabotage, inertia, and innovation (Orlikowski, 2000: 409).

Post-humanist and agential realist proponents, such as Karen Barad, depart more radically from the classic Newtonian concept of matter as a fixed structure by de-emphasizing its agentic physical or logical boundaries and turning matter into a composite assemblage of technology, people, work, and structure in an ongoing intra-action (Cecez-Kecmanovic *et al.*, 2014: 812) as expressed by referring to matter as a verb instead of as a noun – *"matter is substance in its iterative intra-active becoming – it is not a thing, but a doing"* (Barad, 2007: 210).

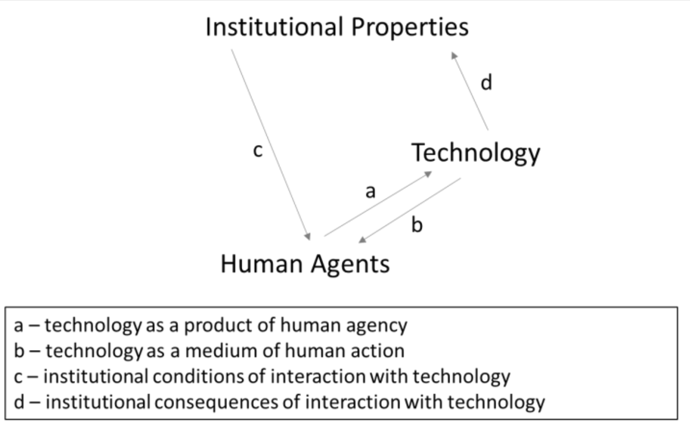
The objective notion that structure is compatible with Human Agency and the strong symmetry between the latter and Material Agency, as articulated in Actor-Network Theory, reinforces the tripartite nature of structure, human agency, and technology (Jones, 1998: 299). Giddens' Structuration Theory attempts to untangle the dichotomy between subjective and objective materializations in that there is reciprocal interaction between humans and structures that enable or constrain them (Giddens, 1984: 8). However, Structuration Theory, as a social meta-theory, does not apply effortlessly to systems and technology, as underlined by Gidden's lack of reference to either. It is true that Structuration Theory fosters the belief that technology is inextricably linked with the social practice in which it is being used and that gives it meaning (Suchman, 2007). However, the complexities of Information Technology, with its tangible (hardware) and intangible (software) components, as well as rapidly evolving user interfaces, require a rearrangement of Gidden's theory. Structuration, much like Actor-Network Theory (Latour, 2005), emphasizes the actions of agents, but ignores the role of Information Technology that would allow users to interpret information as meaningful knowledge (Volkoff *et al.*, 2007: 832).

2.6 Theories and precursory perspectives: Structurational Model of Technology

"There is a distance between the laws of science and the ordinary phenomena of the world…" (Bhaskar, 2013a: 101)

Information Technology is in a multifaceted duality between its constituted nature of being the social product of subjective human action within specific structural and cultural contexts and its constitutive role as a set of rules and resources involved in mediating (facilitating and constraining) human action – it is both preceding and following actions in a non-sequential cycle (Orlikowski and Robey, 1991: 151, 154). As depicted in Figure 2.2, Orlikowski (1992) transposed Gidden's Structuration Theory into the context of IT.

Figure 2.2 – Structurational Model of Information Technology



(Orlikowski, 1992: 410)

In *arrow a* lies the creative human action to design and construct an Information Technology artefact that, by default, will include assumptions and objectives of its designers and engineers (Perrow, 1983: 538-539). In addition, the line from Human Agents to Technology expresses appropriation by users of this technology performing their tasks (DeSanctis and Poole, 1994: 129). The artefact or system in turn mediates (affords or constrains) social practices as expressed in *arrow b* where users exercise the power to choose, or not to choose, using the technology in intended or unintended ways. This freedom of choice (whether to take action or not), inherent in human agency, means that technology can only condition – and never dictate – social practices (Orlikowski and Robey, 1991: 153). Individual actors draw on existing stocks of knowledge, resources, and norms – explicitly and implicitly – to perform their work as highlighted in *arrow c*, mirroring Giddens' Structures of Domination. *Arrow d* demonstrates how technology usage influences Institutional Properties by either sustaining them (through conformance) or undermining/transforming them (through deviation from their sanctioned use).

One example outlining this interaction could be the creation of a collaboration system on a technology platform such as Microsoft SharePoint. The project team may start with a set of requirements that includes the need for frequent exchange of information on specific projects, work tasks, a team calendar, etc. on which the group works together (*arrow a*). Once the functionality has been built, the tool is technically capable of receiving content (*arrow a*). How the solution is operationalized, i.e., what (if anything) gets posted or omitted and the relevancy and/or timeliness of postings, is controlled by each user (*arrow b*). The value of the existing body of knowledge on the platform, supported by rules and procedures (formal norms), as well as what people are expected to do (informal norms) influences what people will do (*arrow c*). This in turn solidifies trends of how the system is being used that subsequently become institutionalized properties of knowledge that can be relevant, unimportant, up-to-date, stale, etc. (*arrow d*). What emerges through the non-sequential pathways of all arrows determines if the system will be an empty shell, a static document repository, or a true collaboration tool among team members.

The forces that permeate this model could over time change entire industries as IT artefacts are socially constructed and can therefore be reconstructed, or changed, by those using it based on different needs, preferences, and experiences (Lawler and Mohrman, 2011: 59). The Structurational Model of Information Technology provides an important underpinning to the Sociotechnical Behavioural Framework in that it connects human agents (Human Agency) and technology (Material Agency) with institutional properties (Interpretive Schema). In the multi-dimensional realm of IoT, however, these connections are not only non-linear but entirely circular. This requires a more integrative lens that recognizes the entangled nature of an activity system.

2.7 Theories and precursory perspectives: Sociomateriality

"Technology and behaviour are not dichotomous in an information system – they are inseparable." (Lee, 2000: 792)

The advent of highly adaptive technology platforms, such as the Internet, Mobile Computing, or Artificial Intelligence, have made the interaction between Human Agency, Material Agency, and Interpretive Schema increasingly unpredictable and unstable (Orlikowski, 2000: 406) where evolving usage patterns and changing requirements constantly prompt new features that will reshape materiality (Schryer, 1993: 204). The outcomes of these agential connections move beyond a reciprocal relationship to an imbricated sequence of visible and self-reinforcing patterns that function interdependently where the resulting structures are *adrift* (Ciborra, 2000) and where the boundaries between humans, technology, and rules are completely assimilated in what Orlikowski and Scott refer to as Sociomateriality (2008: 434, 454).

The notion of merely a structural inscription on technology might have been valid until the 1990s with the development of rigid software applications with embedded rule sets, for example with Enterprise Resource Planning (ERP) systems. However, this view is no longer current as nowadays there is a smartphone application for every evolving need, which in turn produces new needs, and new applications that follow. The resulting structures are no longer embodied, but rather emergent, where all organizational practices and relations always entail some sort of technological (or material) mediation, and where agencies have so thoroughly saturated each other that previously taken-for-granted boundaries are dissolved (Orlikowski and Scott, 2008: 454, 455) in a *"mutual constitution of entangled agencies"* (Barad, 2007: 33). The theory of Sociomateriality thus installs a new view into the relationship between artefacts, agency, technology, and practice (Kautz and Jensen, 2012: 1) and informs Information

Systems research where scholars have traditionally struggled in reconciling human-social and technological dimensions (Kautz and Jensen, 2013: 16). Studies based on Sociomateriality in IT have sharply increased in recent history where in a seven-year time-span, from 2007 to 2013, over 140 journal articles were published that now refer to the concept (Jones, 2014: 895).

This merging of material agency, human agency, and structures forms a collective 'middle space' in what Cook and Brown (1999: 388) have referred to as "practice", Theodore Schatzki calls *"embodied, materially mediated arrays of human activity centrally organized around shared practical understandings"* (Cetina *et al.*, 2005: 11) and in what Wanda Orlikowski outlines as constitutive entanglement (2009: 12) where *"reality is not given but performed through relations in practice"* (Cecez-Kecmanovic *et al.*, 2014: 811).

This expresses how technology has a varying and dynamic effect on people's work and lives by drawing tighter bounds around groups or individuals as the unit of analysis (Orlikowski and Scott, 2008: 456). It assumes that humans and organizations are in interdependent systems that shape each other through ongoing interaction, where the social and physical reality is no longer abstract but rather experienced directly (Yoo, 2010: 218). Thus, rather than users appropriating technology, the starting point is the examination of the human practice and how it enacts emergent structures through recurrent interaction with the technology at hand (Orlikowski, 2000: 407). These reciprocal (inter-)actions occur on two planes: Firstly, in a mental model, at the individual level, where a user observes a technological solution and uses predictive powers to anticipate the behaviour of a physical system while being guided by his or her belief system. Secondly, by recursion between individual agents and the conceptual model that serves as a tool for the understanding and teaching of external structures and the collective human agency (Gentner and Stevens, 2014: 14). The resulting model, like multiple wheels within wheels, leads to complex interacting consequences since the recursive relationship between human agency and social structure is diffuse and structural reproduction is prone to occur unconsciously and unintentionally, resembling imbrication, much like a set of tiles or shingles that overlap on a roof (Ciborra, 2006: 1354). The "playing field" of technology and users is constantly set and reset through these sequencing or interleaving self-contained steps between actions, meaning the application of a technological solution, and its design, meaning the pre-determined functionality, character, and expected social effects (Sein *et al.*, 2011: 39-40) and in what Bhaskar (2010) calls "duality of praxis" as a nod to Gidden's familiar term of "duality of structure".

In expanding the previous example of a SharePoint collaboration project, the omnipresence of ad-hoc collaboration tools such as Slack or Microsoft Teams make the formation and nurture of communities of interest self-sufficient. Where there previously was a defined collaboration project that set out with a charter, requirements, and project structure, there is now a constant ebb and flow in subscriptions or contributions based on people’s real-time interests.

The “duality of praxis” that ensues in the constant blending of settings, re-settings, sequencing, and interleaving between agencies and structures poses a challenge in being able to identify influencing forces. Yet, recognizing them is a prerequisite in the aim to deliberately adjust human behaviour, material designs, or rule sets that govern both. Morphogenesis provides two analytical ‘hooks’ into such an analysis: through examining the degree of separability of the agential and structural blend and by applying the dimension of time. While acknowledging that the system is inseparable in practice, there exists a temporal and analytical separation as an aid to understand the underlying generative mechanisms.

2.8 Theories and precursory perspectives: Analytical Dualism

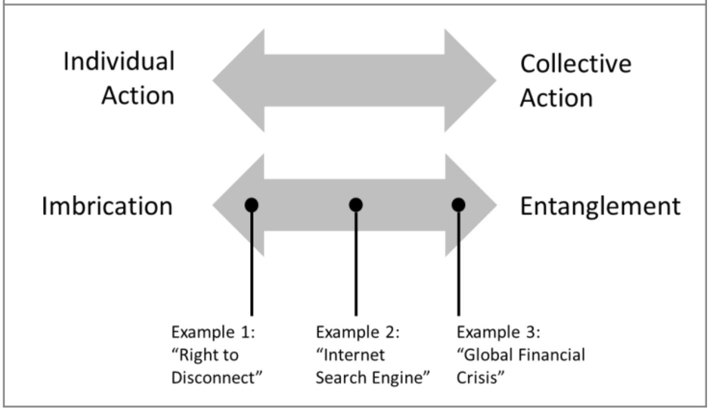
“How to separate what appears to be inseparable?” (Author)

The circular amalgamation of material and human agencies, intermingled with structure, poses a seemingly insurmountable conundrum in distinguishing as to what (or who) is being appropriated by whom (or what). Is an Internet search engine user appropriating technology to find the answer to an inquiry? – or is the search engine algorithm using the individual’s input to customize advertisements? – are both actions taking place simultaneously? – how is the sharing of advertisements based on Big Data influencing cultural societal preferences at the next level in the system?

The proposed instrument for gaining an entry point into this circle (or circle of circles) is the utilization of an instrument of analysis that takes an alternate stance in the argument between relational versus substantialist ontology, Agential versus Critical Realism, and social versus technological determination, and provides for a different view on human agency, technology, and structures. Its aim is to examine, for analytical purposes, and where possible, the individual components that form the recursive relationship between the practice of Human Agency, Material Agency, and Interpretive Schema and to distil resulting unintended consequences.

We can accept the duality in technology that forms dynamic emergent structures, enactments, and a constituted nature of technology. This is the product of subjective human action and an inherent social function – infused into its physical form by designers, regulators, engineers, manufacturers, users, or third parties (Kroes, 2010: 52). The degree of blend, and its counterpoint, the degree of separability, between agency and structure is of importance. Kautz and Blegind Jensen (2012) introduce the nuanced view that *entanglements* as defined by Orlikowski and Scott (2008) are truly inseparable, but Ciborra’s (2006) concept of *imbrications* entails that they are not monolithic and *can* be separated for analytical purposes. The latter are interlocked, like tiles on a roof, and can be carefully unlocked, disconnected, separated, and examined (Kautz and Jensen, 2012: 5) – imbrications are therefore not entanglements (Leonardi, 2013: 3-5). Figure 2.3 illustrates the difference between an imbrication versus an entanglement by overlaying the degree of control that one (or more) individuals is (are) able to exercise in a sociomaterial system (Bratteteig and Verne, 2012: 106-108):

Figure 2.3 – Imbrication and Entanglement based on Degree of Control



The connection between individual and collective action superimposed on a scale of imbrication versus entanglement is illustrated with three examples:

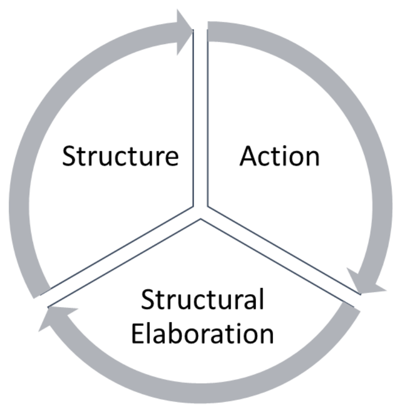
Example 1 (considerable individual action and control) deals with a popular movement in France to disconnect from the office during non-working hours. This is a result of the technical feasibility (Material Agency) afforded by laptops to perform work outside the office. The introduction of mobile phones further "tethered" employees to their jobs by increasing reachability beyond the office and work hours. While some employees resisted these new habits (Human Agency), they found themselves at a disadvantage compared to their more informed co-workers who did not mind keeping up to date with their e-mails, text messages, and voicemails during the evening. The French labour ministry introduced the "Droit à la déconnexion" ("Right to Disconnect") legislation (Interpretive Schema) that obliged companies with more than 50 employees to put processes in place that actively discouraged working outside regular office hours. Since the introduction of the law in 2017, employees have individually exercised their choice to either follow the rule or, in disregarding company policy and peer pressure (Interpretive Schema), continued to answer e-mails during their personal time (Human Agency). The tepid compliance with the new law created an opening for software products (Material Agency) that warn users when attempting to log onto a company's computer system during off-hours. These programs have subsequently curtailed this practice (Human Agency). The example demonstrates that Human Agency, Material Agency, and Interpretive Schema can be isolated into individual building blocks ('roof tiles') and arranged these along a timeline.

Example 2 (less individual action and control) surrounds the behaviour of an Internet search engine. Google, with a near monopoly as a global Internet search site, employs a secret algorithm that constantly recalculates the relative position of a web site within the list of search results. The behaviour of millions of users with their corresponding searches controls the placement of web sites in the results list. Without having direct insight into Google's secret code (Material Agency), it is impossible to map out how individual actions (Human Agency) could result in a web site being on the first page of search results on one day while being relegated to the second page on a different day. The interaction between Human and Material Agency with the software's design (Interpretive Schema) is entangled. Only if specific large-scale events provoke similar searches by millions of users, such as the term "COVID-19", could one isolate the building block of people's behaviour from the corresponding change in Internet search engine results. This makes the behaviour of the page rank algorithm largely unforeseeable as it depends on a significant collective action of millions of people (Bratteteig and Verne, 2012: 107-108).

Example 3 (no individual action and control) looks at the contributing factors to the global financial crisis of 2007 and 2008. Once certain conditions, prompted by human behaviour within the context of an outdated regulatory framework, were set, the avalanche of actions and reactions could not be stopped by individuals who exercise their individual interventions. The defaults of some sub-prime housing loans in the beginning led to the refusal of institutional investors and firms to renew repurchase agreements ("repos"). This quickly led to further price erosions and forced investors to sell assets; resulting in a decline of subprime related bond values that eventually spread to the entire bond market (Gorton, 2010). The crisis spread from the US sub-prime housing market to the entire US economy and eventually to a global recession with negative annual economic growth from the fourth quarter of 2007 to the end of 2009 (Mishkin, 2011). The cycle could only be stopped by massive Government interventions such as more stringent legislation and stimulus packages (Jones, 2009). In this scenario, it is impossible to analyse what specific actions or conditions may have had direct influence over outcomes. The situation represents a true constitutive entanglement with performative powers that have obtained a 'life of their own' (Bratteteig and Verne, 2012: 108-109). This independent life of powers and entities is the essence of morphogenesis (Greek for "beginning of the shape") where processes elaborate or change a system's given form, structure, or state.

If social situations are imbricated via discernible actions rather than indistinguishably entangled, the concept of Analytical Dualism allows us to unravel the dialectical interplay between agencies and structures. In Analytical Dualism, agency is seen as a collective realization across two aspects: First, as <u>primary agency</u> of a collectively unified group with broad cultural belonging to different norms to get accepted as a member of society. Second, as <u>corporate agency</u> that is conducted in the social roles <u>adopted by actors</u>, i.e., persons who are evolving (Archer, 2000). Agency and structure are recognized as interdependent and operating on different timescales in a morphogenetic sequence of structural elaboration (Archer, 2010: 228).

Figure 2.4 – Allochronic Interplay between Structure, Action, and Structural Elaboration



Based on Archer, 2010: 238

Figure 2.4 represents how antecedent structure enables action that produces intended and unintended consequences, which in turn leads to structural elaboration. The elaboration step can be divided into structural reproduction through action that confirms the initial structure (morphostasis) or structural transformation (morphogenesis) where both occur in a non-contemporaneous (allochronic) fashion. When applied to a technology setting, we can probe if the existing structure, such as the design of the technological solution, was followed as expected in what DeSanctis and Poole (1994: 129-130) refer to as faithful enactment. If it was not, through unfaithful enactment, we can discern if this was due to error, i.e. misperception, lack of understanding, slippage – or intention, i.e. sabotage, inertia, innovation (Orlikowski, 2000: 409).

The former (faithful enactment) can be evaluated against the nature of structural elaborations in three modes of interaction: 1) Confluence of desires among stakeholders where overlapping motivations induce a group of people to 'do the right thing', 2) Power induced compliance in being forced by (a) rule(s) to act in certain ways, or 3) Reciprocal value exchange where the expectation of a benefit compels action (Archer, 2010: 235-236). The latter (unfaithful enactment) leads to examining the influencing factors that result in unintended consequences.

In taking a different perspective on the interaction modes of structural elaboration, these can be summarized into three basic mechanisms (Astbury and Leeuw, 2010: 371):

a) situational (macro-micro): where social situations or events shape beliefs, desires, and opportunities of individual actors

b) action-formation (micro-micro): where individual choices and actions are influenced by specific combinations of desires, beliefs, and opportunities

c) transformational (micro-macro): where several individuals, through their actions and interactions, generate transformation

Analytical Dualism opens a window into probing different time intervals where Structure predates action(s) and is followed by subsequent structural elaboration (Archer, 2010: 238); a concept that Giddens does not subscribe to in Structuration Theory as *"social systems only* *exist through their continuous structuration in the course of time"* (1979: 217). It provides for an asynchronous look at occurrences where the initial structure, in the upper left-hand segment of Figure 2.4, resembles the aggregate consequence of prior interaction and where agency applied to action, in the upper right-hand part, can affect the substance of elaboration and/or speed-up, delay, or prevent the elimination of prior structural influences. In completing the circle, structural elaboration, at the bottom of the circle, reflects a host of new possibilities that then re-starts a new morphogenetic sequence of enablement and constraint – comprised of new analytical, conceptual, and theoretical facets (Archer, 2010: 239-241). In revisiting the example of the social construction and reconstruction of the bicycle in Section 2.2 (Merging of the technical and the social), we can now conceptually account for the fact that the transformation of the bicycle from a toy to a practical transportation vehicle took approximately 50 years.

The interplay between structure, action, and structural elaboration gains in complexity when applied to an Information Technology setting. Feldman and Pentland (2003: 95) describe organizational routines as *"repetitive, recognizable patterns of interdependent actions, carried out by multiple actors"*. Within technical systems, these organizational roles are in an embedded relationship with routines and data in an ostensive, i.e. designed, as well as a performative, i.e. applied or 'used', fashion (Volkoff *et al.*, 2007: 833, 838).

The effect of time on evolving phenomena, i.e. how and why things emerge, develop, grow, or terminate, is central to this model as Langley *et al.* (2013) expand upon in the field of process studies. Material systems can only change because of activities that take place <u>over time</u> – whether this is over long periods as in the example of the safety bicycle or through rapidly successive development cycles in modern digital systems where software updates with corrections or functionality additions are rolled-out frequently. Mental systems can change because of intangible flows of interpretation and meaning that result in sudden re-evaluations of norms. These dualities in action create possibilities 'in the moment' that could rapidly flow through the human-cultural system where identifiable discontinuities in this temporal flow allow for the extrapolation of how events bracketed in previous time periods impact subsequent events in current time periods (Langley *et al.*, 2013: 7). As adaptations accumulate over time, there could be large scale tipping points in normative settings that radically revise the interaction process at a transformative level. One example would be the General Data Protection Regulation (GDPR) enacted by the European Commission in 2016/2018 in response to accumulating concerns over data breaches.

Dobson *et al.* (2013) examined apparent issues with widespread Internet broadband adoption in rural Australia in a Critical Realist study. It was the first major work for a tier-one academic journal that utilized Archer's morphogenetic approach in discerning the complex and multifactorial scenarios of technology adoption. These reached across political, personal, and organizational decisions that were shaped by physical, cultural, economic, and ideological elements. The morphogenetic approach, as a basic social concept, provided the foundation to contrast the intimate relationship of broadband usage with rural social dynamics (Dobson *et al.*, 2013: 968).

The ontological proximity of morphogenesis to general systems and process theory positions it for the ‘structured whole’ to be regarded as a collection of social processes where these can be investigated, underlying mechanisms can be identified, and the dynamics that produce such a ‘structured whole’ can be modelled. It posits that emergence is embedded in interaction, it is therefore relational, and it can thus be disentangled into multi-level, constantly interplaying, micro-macro connections with multiple feedback loops. The separation of these various strands is analytically complex since each thread needs to be analysed separately while carefully avoiding omissions or conflations that would inadvertently assign undue primacy to one, potentially incorrect, piece of the puzzle. With careful temporal ordering, it is possible to disengage morphogenic sequences to investigate their internal causal dynamics. Through doing so, it is possible to give empirical accounts of how structural and agential phenomena interlink over time rather than merely stating their theoretical interdependence (Archer, 2010: 245-246).

2.9 Inferential examination of the Sociotechnical Behavioural Framework

“All models are wrong, but some are useful.” (Box, 1979: 7)

The aim of a framework is to describe a set of variables and the relationships among them that presumably account for certain phenomena (Sabatier and Weible, 2014: 6). This provides for a simplified and practical view of reality by making important patterns and relationships visible. The paramount intention is ‘causal honesty’ in that identified pathways within the framework do in fact suggest the relevant conditions that lead to a specific outcome. But, since frameworks and models are a view of reality, and not reality itself, the knowledge used in constructing such an account has the potential to be incorrect in important ways (Morell, 2018: 244-245).

The notions of Sociomateriality within an entangled system as well as Analytical Dualism are incorporated into a new conceptual **Sociotechnical Behavioural Framework (SBF)** that aids in systematically examining each interaction between Human Agency, Material Agency, and Interpretive Schema. It builds upon Volkoff and Strong’s concept that Leonardi’s description of imbrication (2011: 165) of technological events and processes changes routines (Human

Agency) and IT (Material Agency) (2013: 830): The SBF adds the dimension of Interpretive Schema (norms, rules, laws, designs, standards) to the potential for change.

This framework is laid out as a Venn diagram in Figure 2.5 with three interconnected circles representing Human Agency, Material Agency, and Interpretive Schema. These overlap at seven distinct formations (intersections or leaflets) and result in nine different directional flows (arrows) where each intersection and arrow are then used as an analytical probe into the influence of one part over the emergent structure. The latter is expressed as the 'entangled' middle intersection at the centre of all three circles.

2.9.1 Attribution of inter-circle pathways within the SBF

In Chapter 6 (Case findings and analysis), the validity of the framework is examined using actual data from stakeholders (designers, operators, and users) of a technology-enabled car parking solution. Their intentions, as manifested in system designs, business plans, formal and informal rules, expectations, etc., are then being compared with the actual impact by using the intersections and arrows of the framework with the aim to distil the underlying dynamics that have resulted in (an) unintended consequence(s). The framework subsequently proposes an analytical structure through morphogenesis via 'diagnostic hooks' that allow us to inquire as to how the practical application of a given technological solution links back (or fails to link back) to its original intent.

If all three circles always interacted as intended – where assumed technical and procedural norms lead to material affordances that are then utilized by humans in accordance with the design – the consequences would turn out to be as intended. However, unintended actions, conditions, behaviours, etc. in each one of the circles could disturb the interaction overall and thereby lead to unintended consequences.

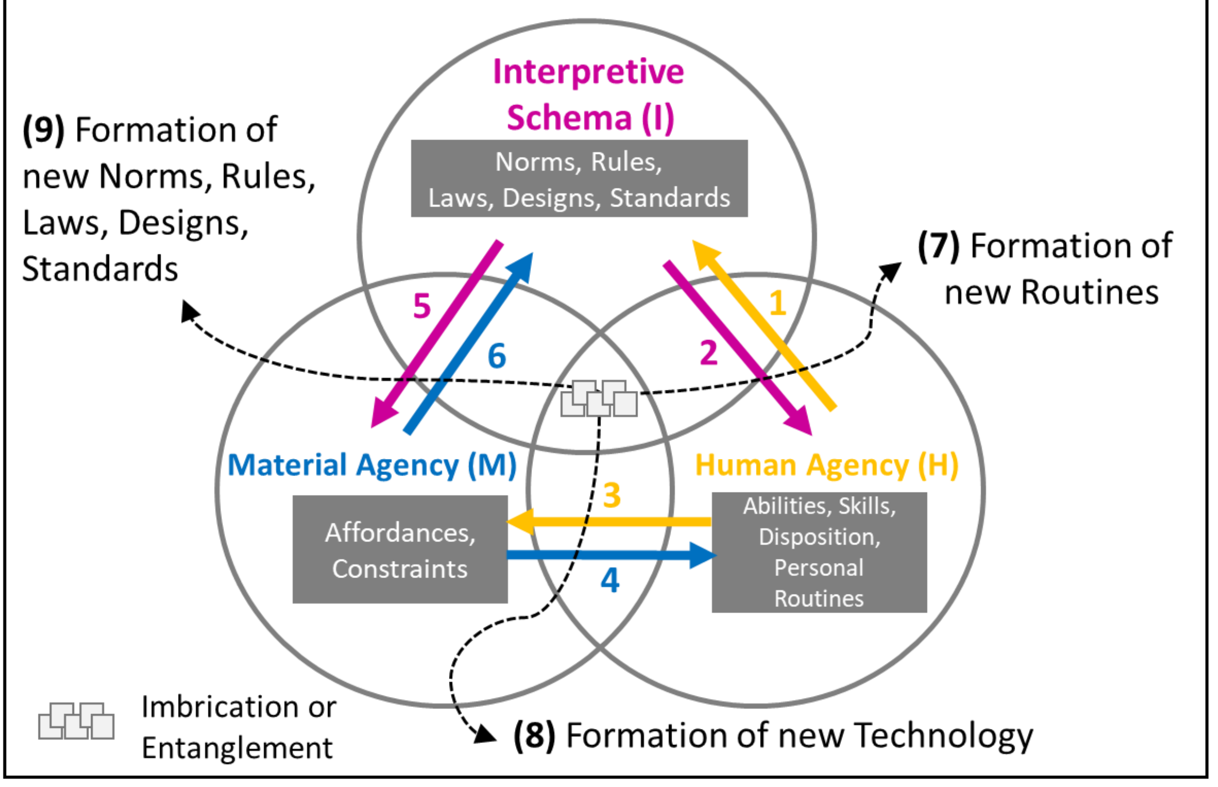
The proposed SBF accepts the constitutive entanglement between all three circles of the Venn diagram but attempts to disentangle individual time-bound connections between each circle. These two concepts are not mutually exclusive – while Gidden's Duality of Structure, i.e. the iterative relationship between human agency and social structure, permeates daily life, it can be strengthened by taking the vantage point of Analytical Dualism in theorizing about variations of voluntary and deterministic actions, temporal structuring and restructuring, and the distinction between subject and object over time (Archer, 2010: 247).

The ever-evolving changes in automobile design, technology, usage, and surrounding rules could be analysed at a point in time with an extrapolation of what contributing factors (human, technology, or rules) influenced the next iteration of the development cycle. An example would be the structural duality of social media sites that represents the entanglement between

Human Agency (participant behaviour), Material Agency (platform features), and Interpretive Schema (privacy laws, system designs, social standards). All three influence each other over time: users post, the platform designers introduce new features, user adoption grows, the provider recognizes the monetary value in the information stored, outside companies are allowed to access personal data for commercial and/or political purposes, system designs (and ultimately privacy laws) change, users modify their behaviour or chose to change contents and habits of posting, the platform design takes such changes into account – and the cycle continues in ongoing gyrations. Yet, the cycle can be stopped, analytically, and the duality of the system can be broken down into its dualistic (component) entities at that given point in time (such as when it became known that the platform forwarded personal data to companies without the user's consent). The examination of such an analytical slice could lead to possible corollary explanations of influences exerted, path dependencies followed, and potential causalities inferred.

This provides the starting point for drawing the map of the territory as an attempt to arrange duality and dualism as a theoretical model of abstraction (Korzybski, 1951). The impact of technology solutions on the social use and on subsequent behavioural consequences is critical in the attempt to answer the research questions and prompts this new conceptual lens of the SBF to crystallize unintended consequences. Figure 2.5 is an illustration of the framework outlining the interplay between Human Agency, Material Agency, and Interpretive Schema with all possible nine directional pathways:

Figure 2.5 – Sociotechnical Behavioural Framework (SBF)



The directional pathways are depicted by nine arrows that cross the framework's intersections: Arrow 1 signifies the influence of Human Agency onto Interpretive Schema, such as where the personal routines of a group give way to a new societal standard. One example would be the practice of shaking hands that was replaced by exchanging fist bumps to limit the spread of infection. Arrow 2 describes an influence in the opposite direction – for example an employer who enacted the rule of casual Fridays that resulted in employees dressing differently on that weekday. Arrow 3 shows an influence of Human Agency over Material Agency, such as where the disposition of protesters alters the Material Agency of a street (the change from a thoroughfare for traffic to a gathering place for communicating a message). Arrow 4 directs the Material Agency of an object towards Human Agency, with an example being smartphones and tablets that largely supplanted reading newspapers with checking such devices during the daily morning commute on public transportation. Arrow 5 indicates the influence of Interpretive Schema onto Material Agency where an example would be data privacy laws that guard methods of information storage and retention in IT systems. Arrow 6, the effect of Material Agency onto Interpretive Schema, could express that the ability and practice of IT systems to hold vast amounts of personal data prompted the need for a modulating law.

Arrows 7 through 9 act differently in that they originate in the *constitutively entangled* middle space of the three-ring intersection. These arrows signify change and the formation of new routines, technology, or rules. In the example of data privacy laws, all three circles are at play: Interpretive Schema (the law), Human Agency (the desire for the law and the application of it in people's daily lives), and Material Agency (the system's ability to act according to the law). It is the dimension of time that allows to suggest which arrow would have been activated first, second, third, etc.

The advent of on-line shopping activated arrows 7, 8, and 9 through the formation of new routines (people buying through the web), new technology (e-stores), and new laws (data privacy). The introduction of new data privacy laws and designs can be broken down into time-phased instantiations that trace through the arrows of the framework:

The affordance of e-commerce enabled websites to prompt shoppers to make on-line purchases part of their personal routines (arrow 4), which led an increasing number of people to develop the new norm of entering their credit card information (arrow 1). The disposition of this large consumer base to shop on-line prompted more traditional retailers to offer e-commerce capabilities (arrow 3). The negative affordance of an unprotected system to make credit card information available to non-authorized users triggered for the legislator to act (arrow 6). New obligations resulting from new data privacy laws, standards, and designs are incorporated in the system (arrow 5). These laws influence the disposition and personal routines of users to expect for on-line retailers to protect their data and for users to be generally more prudent in giving out credit card information (arrow 2).

The framework therefore reveals the analytical morphogenetic pattern change across multiple directional arrows to distil unintended consequences. By lining-up the framework to start with a description of affordances provided by a novel technology, it contributes to the *"demand in the Information Systems literature for mid-range theories that provide explanations of causality at a level of granularity that is specific with respect to the technology while also providing some generality beyond individual case examples"* (Volkoff and Strong, 2013: 828).

2.10 Conclusion of the literature review

> *"Theories are nets cast to catch what we call 'the world': to rationalize, to explain, and to master it. We endeavour to make the mesh ever finer and finer." (Popper, 1959: 59)*

The key finding of this literature review is a gap in the field of recent sociotechnical research with regards to analytical tools that allow for the examination of generative mechanisms in systems development. With the understanding of these mechanisms come opportunities for improvement – particularly in the fast-moving technology sector of IoT technologies.

The review of the extant literature led to the construction of the Sociotechnical Behavioural Framework. The first step in building the framework has been synthesizing and contrasting several related theories: Affordance Theory for describing material capabilities and their use, Structuration Theory that integrates human agency with the surrounding social structure, and Adaptive Structuration Theory where an object's capabilities are ultimately linked to the designer's intentions.

The Structurational Model of Technology further set the stage for intertwining relationships between humans, technology, and rules, that ultimately resulted in the theory of Sociomateriality. The Sociotechnical Behavioural Framework embraces Sociomateriality's central tenet of the entangled, unpredictable, and unstable fusion of the technological, human, and structural/interpretive realms (Orlikowski and Scott, 2008: 434, 454). This is expressed in the three-ring overlap of the Venn diagram that consists of Interpretive Schema (norms, rules, laws, standards, designs), Human Agency (abilities, skills, disposition, personal routines), and Material Agency (affordances, constraints).

The review of the literature also gave rise to the possibility of analytically tracing changes to interlocking and temporally complex agential and social structures within technology systems. This is ontologically consistent with Sociomateriality's inherent concept of entanglement between the technical, the human, and the structural. The epistemological complement is a form of Margaret Archer's Analytical Dualism (2010) that examines how processes elaborate and change a system's form, structure, or state over time.

It is important to note that the Sociotechnical Behavioural Framework is still tentative at this stage. The framework will be further amplified through thought experiments, which one might expect to follow this literature review. However, a thorough account of the rationale for a Critical Realist view is fundamental in positioning the thought experiments. Therefore, the following Chapter 3 (Research methodology and design) describes the paradigmatic underpinnings that enable the extended epistemological view onto Sociomateriality through the meta-theory of Critical Realism. This is then followed by Chapter 4 (The Sociotechnical Behavioural Framework in thought experiments).

3 Research Methodology and Design

"What counts for the truth can vary from place to place and from time to time." (Collins, 1983: 88)

How we perceive the nature of the world (ontology) influences what we think we can know about the world (epistemology), which in turn affects investigative techniques (methodology and research techniques) that we seek to employ in gaining this knowledge (Fleetwood, 2005: 197). The logical connection between an ontology, epistemology, and methodology is summarized as a paradigm, i.e. a set of basic beliefs (metaphysics) that deals with first principles, represents a worldview adopted by groups of researchers, and positions an individual's place in it (Guba and Lincoln, 1994: 107). The selection of the paradigm, and with it the associated ontology, epistemology, and methodology is a vital component of every research project. It determines the practical modalities of the work, such as the design of the study, and it directly reaches into the nature of the conclusions to be drawn (Khaldi, 2017: 16). The subsequent sections in this chapter lay out the case for the chosen paradigm for this thesis. It brings forward the argument for its ontological choice of bridging the relativist and realist traditions.

Situated at the extreme end of the relativist-realist spectrum, at the pole of relativism, lies Karen Barad's Agential Realism that, by utilizing metaphors borrowed from quantum mechanics, regards the social and the material as completely inseparable (Barad, 2007). The meta-theory of Sociomateriality builds upon this view by rejecting the dissociation between technology, work, and organizations. It argues for the inherent inseparability between the technical and the social (Orlikowski and Scott, 2008: 434) where distinctions between human and non-humans disappear in a constitutive entanglement (Scott and Orlikowski, 2014). At the other end of the spectrum lies the realist non-conflation of the material and the social. In negating a central tenet of Sociomateriality, it proposes to simply hold the material and the social apart for analysis (Mutch, 2013).

System designers and policy makers in the Information Technology realm struggle with conceptualization, design, and implementation of effective technology solutions that are fit for purpose as far as (human) users are concerned. The acceleration of the technology lifecycle and the advent of new technologies, such as IoT, only exacerbate the problem. This thesis aims to contribute to this discussion by offering an alternate and innovative ontological, epistemological, and methodological approach.

It accepts and advocates the main idea of Sociomateriality in that observed phenomena in the sociotechnical realm are, *in their outcome*, indistinguishable as an amalgamation between technology and humans. In addition, it recognizes the need for designers and policy makers to have instruments that allow some degree of analytical separation to infer the underlying generative mechanisms that might spark further understanding of the complexity of these man-made intelligent systems. Without such instruments, any attempt to design new (or improve existing) 'fit for human purpose' systems, especially in the fast-moving technology field of IoT, would be haphazard at best.

This thesis proposes shifting the 'material versus social' discourse towards the centre of the relativist-realist spectrum by offering a view onto Sociomateriality through the lens of Critical Realism (CR). It brings the benefits of CR to Sociomateriality by adopting CR's stratified reality that separates observations from experiences and isolates them from their causal generative mechanisms. This represents the first entry point of the analysis in ontologically differentiating the social and the material. It is consistent with Niemimaa (2016: 48) in that CR is able to incorporate aspects of other world views such as in the positivist, interpretive, and critical spheres. The second entry point is the introduction of time as an essential element in exploring the relationship between structure and agency, and with this, between the social and the material. This takes place through the application of Margaret Archer's theory of Analytical Dualism, which holds the belief that the sociotechnical constitutive entanglement can be penetrated via time-based slices of prior structures, actions, and resulting new structures (Archer, 2010: 228, 238).

The argument for this novel approach in the field of Information Technology starts out with a comparison of the ontology, epistemology, and common methodologies in Table 3.1. It juxtaposes four major scientific paradigms as adapted from Guba and Lincoln (1994) and Perry *et al.* (1997: 547). All four paradigms are valued by Critical Realists where Bhaskar sought to recognize the concepts and underpinnings of each through a stratified ontology that gives rise to a more complex phased logic of inquiry (Niemimaa, 2016: 48):

Table 3.1 – Four categories of scientific paradigms and their elements			
Positivism	**Critical Theory**	**Constructivism**	**Realism**
		Ontology	
Reality is real and apprehensible	'Virtual' reality shaped by social, economic, ethnic, political, cultural, and gender	Multiple local and specific 'constructed' realities	Reality is 'real' but only imperfectly and probabilistically apprehensible

Table 3.1 – Four categories of scientific paradigms and their elements			
Positivism	**Critical Theory**	**Constructivism**	**Realism**
	values, crystallized over time		
Epistemology			
Objectivist: findings true	Subjectivist: value mediated findings	Subjectivist: created findings	Modified objectivist: findings probably true
Common Methodologies			
Experiments/surveys: verification of hypotheses, chiefly quantitative methods	Dialogic/dialectical: researcher is a 'transformative intellectual' who changes the social world within which participants live	Hermeneutical/dialectical: researcher is a 'passionate participant' within the world being investigated	Case studies/convergent interviewing: triangulation, interpretation of research issues by qualitative and by some quantitative methods such as structural equation modelling

3.1 Choice of ontology and epistemology

"The social world is complex and full of random noise that may obscure the processes we are interested in." (Leifer, 1992: 286)

This thesis links research on technological solutions with the social settings in which they are being used. It thus presents a challenge as to the nature of this reality (ontology) and whether it should be primarily examined through the 'prism of machine or man' versus an interdependent and mutually co-constituting lens. The choice of ontology and epistemology for this thesis is supported by Easterby-Smith *et al.*'s observation that recent qualitative studies have been successful in opening up new perspectives (2008: 484) and resembles an exploratory order of abstraction in support of Kuhn's (2012: 29) argument of likely paradigmatic ambiguity when inquiring about qualitative aspects of nature's regularity.

This exploratory requirement is met through abductive, retroductive, and retrodictive logic of inquiry that attempts to colligate observable data from the world of human-technology interaction with existing theory and a critical concern for surfacing the unobservable mechanisms at an abstract level (MacCorquodale and Meehl, 1948: 95). This step in the process is *"often a messy one where perspectives, approaches, and views, that are not yet theory still guide research"* (Priem and Butler, 2001: 57) and where this theory elaboration distils phenomena into sharp distinctions (Suddaby, 2010: 346-347).

In developing this construct, the ontological choices range from Realism with the belief in a single truth to Nominalism with the principle that there is no reality and only the description of objects, properties, and man-made categories of experiences and events. Easterby-Smith *et al.* (2012: 19) summarize the nuances of what 'truth' and 'facts' signify for four major ontologies that are summarized in Table 3.2:

Table 3.2 – Ontology with distinction between truth and facts

	Realism	**Internal Realism**	**Relativism**	**Nominalism**
Truth	Single truth	Truth exists, but it is obscure	There are many 'truths'	There is no truth
Facts	Facts exist and can be revealed	Facts are concrete, but cannot be accessed directly	Facts depend on viewpoint of observer	Facts are all human creations

The individual experiences of technology users when engaging with technology point to a multiplicity of 'truths' as described in Relativism – with the additional facet being that these 'truths' are not only discovered, but in fact created, by the people who utilize such technological solutions (Latour and Woolgar, 2013: 179). These 'truths' are constantly changing and therefore not easily measurable since the context in which they occur is vitally important (Merriam, 2002: 3-4). The examined technological systems are highly complex, emergent in their properties, and non-linear in their behaviour where the interaction between component parts cannot be sufficiently predicted. Their behaviour cannot be deduced based on observable phenomena since, in living systems, the whole is more than the sum of its parts (Levy, 1992: 7-8).

The distinct irreducible character between 'things' and 'humans', in what Latour (2005) labelled human and non-human actors in Actor-Network Theory (ANT), disappears and becomes boundaryless. In this sense, anthropocentrically driven interactions that originate in 'humans' and extend to 'beings' become mere intra-actions within 'beings' (Barad, 2007) – whether they are human or non-human. Scott and Orlikowski (2014) transpose this thinking onto the complex and interactive ('intra-active') world of social media websites where any distinction between human and non-human actors seems to have vanished. In this sense, the exchange has become an intra-action within 'beings'.

This is consistent with Agential Realism and its denial of any separability between technologies, technology use, the social, the material, structure and action (Leonardi, 2013: 65). Agential Realism regards the *social* and the *material* as entirely inseparable, akin to the concept of 'entanglement' in quantum mechanics (Barad, 2007) where the *social* and the *material* are selective projections of a *tangled whole* (Mazmanian *et al.*, 2014: 832).

The apparent obstacle of conducting analysis under the principle that the *material* and the *social* are inseparable, at any level, is indicated by the scarcity of Information Technology research with such relativist underpinnings (Hultin, 2019: 93). This is supported by researchers such as Wagner *et al.* (2010: 293) who encountered the challenge of not switching between the distinctly *material* and the *social* when looking at technology solutions in practice such as off-the-shelf Enterprise Resource Planning (ERP) applications and misalignments that occur during their implementations.

As an alternate path, several researchers argued for a turn towards Realism in the examination of human, technology, and societal aspects. The position of Critical Realism (CR) is helpful where it is critical towards the assumption that science should accept many truths permanently. CR wants science to progressively work towards understanding the deeper hidden truths that are always still tentative, but that are also generative of the complexity of the world and help us understand the roots of emergence.

Mutch (2013) proposes a non-conflationary style where the material and the social are held apart for the purpose of examining their interplay. He sees Margaret Archer's morphogenetic approach (2010) of stratification, emergence, and the importance of time, essential to exploring the relationship between structure and agency and between the social and the material (or technological). Even if the boundaries of the social and the material are indistinguishable up close, at the micro level, realists can apply a toolset that allow a discerning of components in the social-material relationship at a macro level (Mutch, 2013: 38).

CR has the ability to subsume positivism, interpretive, and critical world views (Niemimaa, 2016: 48). It acknowledges Sociomateriality at the actual level but seeks to probe deeper to uncover the unobservable mechanisms that combine to form the tangible whole. Specifically, CR provides an answer to the ontological separation between the social and the material by assigning them to different temporal realms to examine the process of becoming a Sociomaterial entanglement.

It argues that structure predates action, i.e., the use of technology, and that structural elaboration postdates the action. In this sense, a hammer is a material (not a social) object, its structural property (affordance) is to amplify force and driving a nail into the wall is the action (technology use) that is performed with the instrument. The *social* and the *material* are therefore independent and become the *sociomaterial* through human action (Leonardi, 2013: 66, 68-69).

This study accepts the nature of sociomaterial entanglement but adopts a CR ontology to support the primary purpose of the study, which is to distil the unintended consequences that result from the material and social interaction.

3.1.1 Comparison of different types of Realism

> *"Social change is evolutionary – path-dependent yet contingent, shaped by legacies yet affected by contingently related processes or conditions"*
> *(Sayer, 1999: 26)*

Three distinctive forms within the broad ontological field of Realism have emerged that are guided by the maxims of a *single truth* and *existing facts* (Easterby-Smith *et al.*, 2012: 19):

Scientific Realism, which bears a philosophical association with Positivism. This can be problematic in social science because the expectation of objectivism can only be certifiable inter-subjectively (Boal *et al.*, 2009: 10). The researcher, who views the world through the objective 'one way mirror', must demonstrate how s/he has managed their own subjective values to avoid biases that in turn influence outcomes (Guba and Lincoln, 1994: 110). Scientific Realism entails principles that are publicly verifiable, rational in their development, with a truth-content demonstrably greater than that of rival contenders, and with reliable criteria by which to evaluate subsidiary beliefs and hypotheses (Beach, 1984: 159).

Theoretical Realism, which theorizes about reality on the opposite pole of a Positivist appearance and derives explanations that depend on the belief in an imputed *a priori* theory. Theoretical Realism is committed to the formulation of macro-theoretical propositions about universal features in social reality, which can be deducted from a relatively small number of core behavioural axioms (Somers, 1998: 4, 15).

Critical Realism (CR), which distinguishes *the world* (physical or social) from our *knowledge about the world*. CR conceptualizes reality as occurring on three separate planes: The *real* where the physical or social simply exist as powers or tendencies of a system of objects. This plane contains embedded structures with affordances and constraints that include causal liabilities, which are independent from what we know about them. The *actual* that is concerned with the effects once these powers are activated and the *empirical* where these effects are being experienced. At times, there may be a clear line of sight between the *empirical*, the *actual*, and the *real*, but some structures may not be observable. While observability increases confidence in the answer, observability is not a prerequisite for such an answer, and CR accepts causal inferences when observable effects can be explained by the existence of unobservable entities (Sayer, 1999: 10-12). In providing an example, a theatre production company is the *real*, a play's performance is the *actual*, and the audience's experience is the *empirical*. One observable structure is the clear connection between the viewer's *empirical* experience of Juliet's struggles in her relationship with Romeo to the *actual* excellence of the performance and to the *real* abilities of the actors. An unobservable structure is the causal inference of the existence and powers of Shakespeare, as the playwright, and of the play's director as causal liability to a high-quality production.

3.1.2 The case for Critical Realism

"There is no escape from philosophical assumptions for researchers"
(Hammersley, 1992: 43)

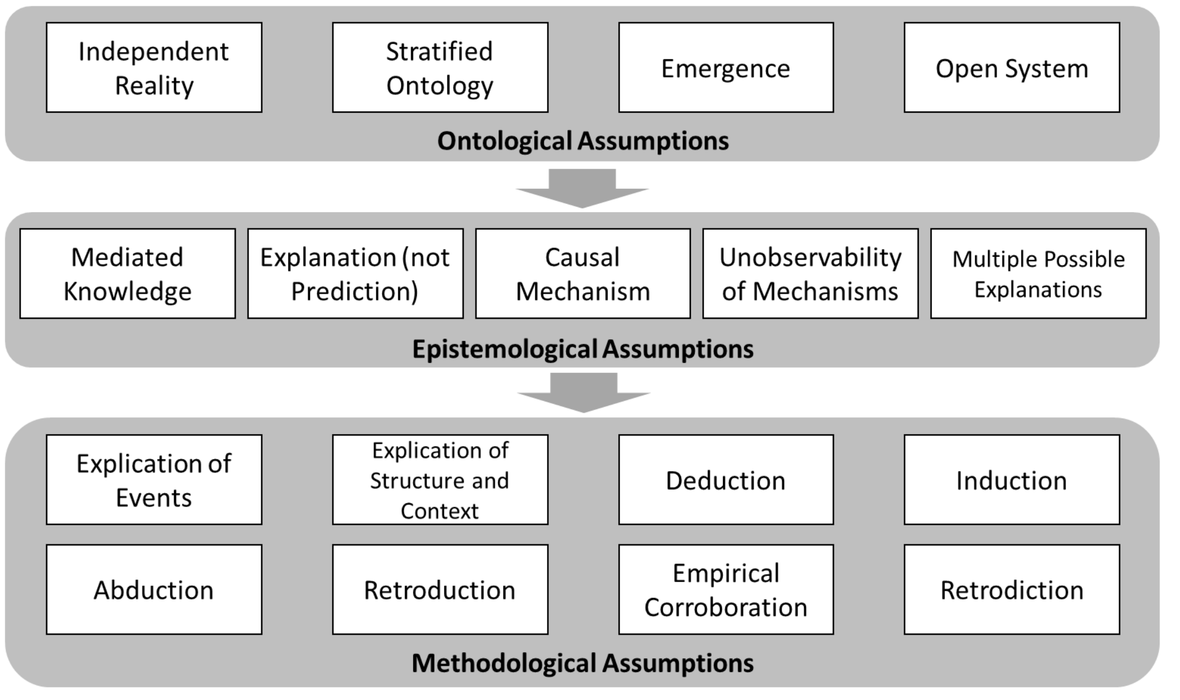
CR offers an integrative position that honours the tenets of both Positivism and Constructionism (Easterby-Smith *et al.*, 2012: 29) and introduces a compelling third way that seeks to avoid the problem of mistaking epistemology for ontology. It lies between the more 'extreme' poles of Positivism and Interpretivism by having evolved as a distinctive meta-theory and philosophy of science within the Realist intellectual tradition (Sayer, 1999: 2-3). Positivism embodies the notion that organizations evolve independently of social relations, while Constructionism sees organizations as configurations of social practices with its structural properties and institutional logic and where reality is dependent on human knowledge (Reed, 2011: 7, 9).

CR has been recognized as a broad ontology and epistemology across a variety of research disciplines. However, CR has so far been largely confined to social research. It builds a bridge from Positivism to Constructionism, and in so doing, opens the potential to branch from social science into Information Systems (IS) theory by allowing us to ask 'why' questions that are prevalent in IS research (Smith, 2006: 193, 207).

CR has thus gained a foothold in social science and Information Technology (IT) research as an alternative to the more prevalent paradigms of Positivism and Interpretivism. It spans the breadth of IT, social, organizational, and environmental factors when attempting to address causality, and – through the vehicle of a case study – seeks to develop causal explanations of complex sociotechnical phenomena, happenings, or outcomes (Wynn Jr and Williams, 2012: 787, 797). While the meta-theory does not specifically address the topic of technology in organizational settings, it lends itself to an easy conceptualization of structural conditions encountered by agents. Through this, it provides *"an ideal perspective for developing midrange theories of technology-mediated organizational change"* (Volkoff *et al.*, 2007: 835).

CR is realist as a defence against Positivism that sees the world as a conglomerate of empirical observations and measurements and as a defence against Constructivism that regards the world as the sole representation of human knowledge. It is critical in a Kantian sense in that access to this world is mediated by our own perceptual and theoretical lenses (Mingers *et al.*, 2013: 795). It adopts a relativist epistemology, in which causality is dependent on context. Figure 3.1 highlights the ontological, epistemological, and methodological interdependencies, which are further described in the subsequent sections of this chapter:

Figure 3.1 – Ontological, Epistemological, and Methodological Assumptions of Critical Realism



(adapted from Wynn Jr and Williams, 2012)

3.1.2.1 Critical Realism – ontological assumptions

> *"If science is to be rendered intelligible the world must be seen as one of persisting things, of differing degrees of structure and complexity, to which powers and tendencies are ascribed" (Bhaskar, 2013a: 175)*

CR introduces the concept of an **independent reality** as two sides of knowledge: It separates *the world* as an entity that consists of physical processes and social phenomena (referred to as the *intransitive dimension*) from what we *know about the world* through existing theories or other scientific concepts (referred to as the *transitive dimension*). The latter can evolve through new or rival transitive objects of knowledge (theories) while the former, the intransitive dimension, remains unchanged – much like the earth did not physically change from 'flat' to 'round' with the introduction of Galileo's theory (Sayer, 1999: 10-11). The *intransitive dimension* consists of an independent reality that is not easily apprehended or perceived and that can exist autonomously without someone observing, knowing, or constructing it. It is as such a collection of 'brute facts' that reside independent of human beings and their institutions (Smith and Searle, 2003: 285). In this sense, the *transitive dimension* can only be a subset of the *intransitive dimension*. This also applies to social settings where social actors may only tacitly know how to do something without the ability to articulate their knowledge about it (Fleetwood, 2005: 197). The *transitive dimension* is comprised of antecedental established knowledge, which is under constant anthropocentric revision and reinterpretation through science and reason, that is used to explore the unknown (but knowable) *intransitive structure* of the world. The clear separation between the *intransitive* and *transitive realms* also means that a given actor operates in the *transitive* reality and does not influence the *intransitive* reality through his or her socially constructed view.

We gain understanding of *intransitive* objects of knowledge through our understanding of *transitive* objects of knowledge in a manner that is differentiated, constantly changing, and out-of-phase with one another (Bhaskar, 2013a: 13, 15). In CR, the *intransitive* and *transitive* dimensions are entirely separate and presuming that an entity must be known in order to exist is akin to committing the epistemic fallacy of conflating ontological with epistemological concerns (Fleetwood and Ackroyd, 2004). Our documented understanding of the *intransitive* real abilities of the actress playing Juliet is gained through the critic's *transitive* evaluation of her performance. But, in holding true to CR's ontoepistemological orientation, it is entirely possible for Juliet to be an exceptional actress even if the theatre critic has not yet had the opportunity to know how she plays the role.

CR accepts a **stratified ontology** in three nested domains: through senses or measurement (the *empirical*), through events that are enacted in a visible or hidden fashion (the *actual*), and in the independent existence of structures and causal powers of objects (the *real*) that may also be visible or hidden. An example of a causal power or mechanism that is hidden is market dynamics where buyers and sellers gravitate towards market efficiency by agreeing on a price that is acceptable to both (Bygstad *et al.*, 2016: 2). This ontological stratification provides the epistemological foundation for CR in that it is anti-empiricist, for mechanisms may be present in the *real* that are imperceptible, and anti-conventionalist, since limited knowledge of 'being' is not a limitation on 'being' itself (Mingers *et al.*, 2013: 796).

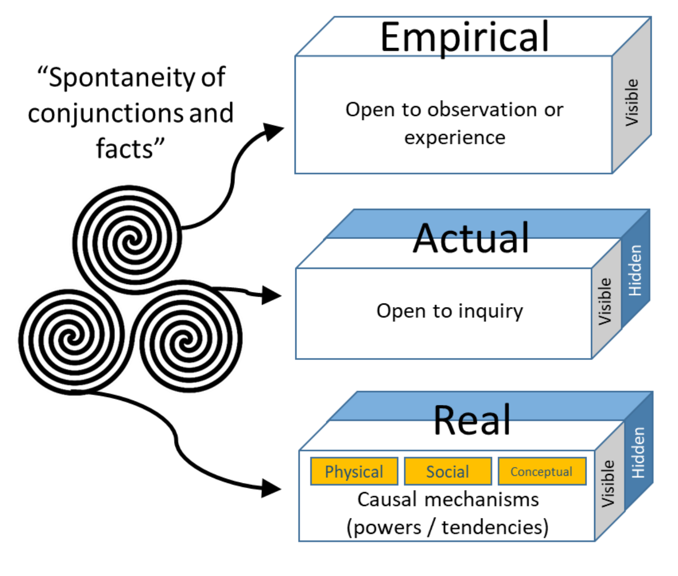
This stratification of reality is a cornerstone of CR in emphasizing that the two – ontology as the nature of reality, and epistemology as the knowledge of reality – occur on different planes.

It does not regard knowledge as a lens on reality, such as in positivism, nor as a container for reality such as in constructivism (Fletcher, 2017: 4).

The three domains are interconnected through complex processes and relations that cannot be reduced to or collapsed into each other but that give rise to new and innovative potentialities through the emergence between mechanisms that cross these planes. In this sense, social reality is neither confined to nor explained by solely the empirical (Wuisman, 2005: 368). It rather follows a path of reduction from the real to the actual and to the empirical in a spontaneity of conjunctions and facts (Bhaskar, 2013a: 49). This path resembles a one-way street in the explanation of phenomena: The lower strata mechanisms can explain a perceived or experienced event, but they cannot be reduced to those mechanisms because higher level strata always have an element of emergent properties (Niemimaa, 2016: 49). As an example, the person running a marathon will experience an elevated heart rate as a physiological change, but this change cannot be entirely reduced to the mechanism of running.

Figure 3.2 graphically depicts CR's three stratified planes:

Figure 3.2 – Critical Realist Stratified Ontology



(after Bhaskar, 2013)

At the top is the *empirical* domain that provides a window onto observable phenomena or experiences. The *actual* domain in the middle consists of events that occur visibly as well as in a hidden fashion. The domain of the *real* (bottom) can be further divided into three entity classes as shown in the orange-coloured boxes: enduring physical objects such as atoms or organisms, social entities such as 'the market', 'family', or a 'user community', and conceptual entities such as categories or ideas. These may be visible or hidden (Mingers *et al.*, 2013: 796). Objects (entities) are distinctly different from variables that are prevalent in most social research traditions: entities are things whereby variables are measures of things – since the *real* consists of things, they are deserving of research into their fundamental nature and capabilities rather than their measurable properties. This represents a shift from epistemology and methodology to ontology (Easton, 2010: 120).

There exists a *"set of internally related objects or practices"*, whether they are physical or logical, in CR structures, that resemble the *real* entities under investigation in a contextual situation (Sayer, 1999: 11). Structures themselves can be stacked upon each other through the process of lamination in what then results in assemblages (DeLanda, 2019), which are not just additive components, but form emergent causal properties. While structures and assemblages reside in the realm of the *real*, the knowledge about them is formed in the transitive *empirical* dimension and mediated by our experiences, values, social structures, and existing theory (Elder-Vass, 2007: 3).

The interlacing spirals in Figure 3.2 signify dialectical generative mechanisms at work that result in the presence (or absence) of actual events and their corresponding observations or experiences (Mingers *et al.*, 2013: 796). CR adopts a relativist position since it promotes the possibility of finding explanations for underlying and unobservable mechanisms in the independent *real* on the basis of observable phenomena that occur on the plane of the *empirical* (Reed, 2011: 8). Bhaskar stressed that *"[…] for CR, there is no incompatibility (but rather mutual entailment) between ontological realism and epistemological relativism, and between both and judgmental rationalism"* (Bhaskar, 2013b: 34).

Mechanisms are *"underlying entities, processes, or structures which operate in particular contexts to generate outcomes of interest"* (Astbury and Leeuw, 2010: 368). They are a causal power, such as an inherent tendency, capacity or disposition, of the system to do something that may be realized, or not if it is impeded, in which case the outcome may not manifest (Manicas, 1987: 41). As such, generative mechanisms are related to affordances in that they contain a capacity for action that is realized in the interaction between objects and actors (Volkoff and Strong, 2013: 832). Bhaskar emphasized that our understanding of the world consists of mechanisms and not events and that the conditions under which these causal mechanisms (powers or tendencies) are being activated can be found through intellectual, practice-technical, and perceptual skills (2013a: 37, 56). Here, conceiving affordances also act as building blocks of mechanisms so that relationships between function, structure, and identity can be described and analysed in detail. It thus allows the researcher to 'zoom in' and 'zoom out' in constructing explanations (Bygstad *et al.*, 2016: 11).

Hedstrom and Ylikoski (2010: 3-5) attributed five characteristics to mechanisms: 1) the production of an effect or phenomenon, 2) the possession of an irreducible causal notion, 3) the presence of structure, 4) the formation of a hierarchy, and 5) the possibility for combination.

Bernoulli's principle outlines that the shape of an airplane wing does possess the causal mechanism to create lift even if the plane is currently parked on the ground – it is not about what an airplane wing does but about the *power of what it can do*. Mechanisms reach beyond the nomically qualified exercise of powers into intrinsic enabling conditions that something is predisposed or oriented towards – with an example being that all men possess the power to steal, and kleptomaniacs possess the tendency to do so. The distinction between tendencies and powers addresses the incongruency of some behaviours being atypical and some events being uncaused (Bhaskar, 2013a: 171, 222).

When applying Hedstrom and Ylikoski's five characteristics of mechanisms to Bernoulli's principle, we see that 1) the airplane flies (effect or phenomenon), 2) the airplane's thrust and upward lift keep it in the air (irreducible causal notion), 3) Newton's third law of motion stipulates that for every action there is an equal and opposite re-action (structure), 4) the laws of speed and aerodynamics work together (hierarchy), and 5) thrust and lift keep the airplane flying (combination).

Events occur in the *actual* plane because of one or more mechanisms that are enacted in the *real* plane – whether they are visible or not in the *empirical* realm. In case events are observable in the *empirical* realm, CR refers to these as experiences; by default, experiences are always a subset of events (Wynn Jr and Williams, 2012: 792).

Structural **emergence** signifies that entities can exist at various levels of aggregation where understanding their <u>emergent properties</u> through a summative process or a reductionist approach (top to bottom) is not necessarily possible (Easton, 2010: 121). This is especially applicable with social structures that are irreducible to their lower-level powers, with an implied discontinuity between their initial interactions and the complex system as their product (Archer, 2010: 228), again underlining the ontological character of (emergent) objects/entities (Bhaskar, 2013a: 103). This process of emergence equips structures with unique properties – with water being an example, in that it is composed of hydrogen and oxygen, yet the emergent property of water is distinct in itself (Wynn Jr and Williams, 2012: 791). In addition to emergent structures possessing unique characteristics, they also have causal powers (Elder-Vass, 2007: 6) in that water flowing through turbines under a hydroelectric damn has different effects than its compositional substances of hydrogen and oxygen.

CR sees reality as an **open system** with all its inherent complexities and plurality of causes: structures (objects or entities) extend across the physical and the social world – whereby the latter constrain or enable social activities, are themselves reproduced or transformed by these activities, and do not exist independently of the agent's conceptions of their own activities set within the structures. Social structures, such as individuals, groups, churches, gangs, or organizations, are by nature volatile and present an open system with unstable empirical relationships (Bhaskar, 2013a: 64, 239). They are simultaneously autonomous from individuals while being dependent on their activities (Smith, 2006: 202) with outcomes that are nondeterministic, but probabilistic, and contingent on other mechanisms in the open system (Bygstad *et al.*, 2016: 1).

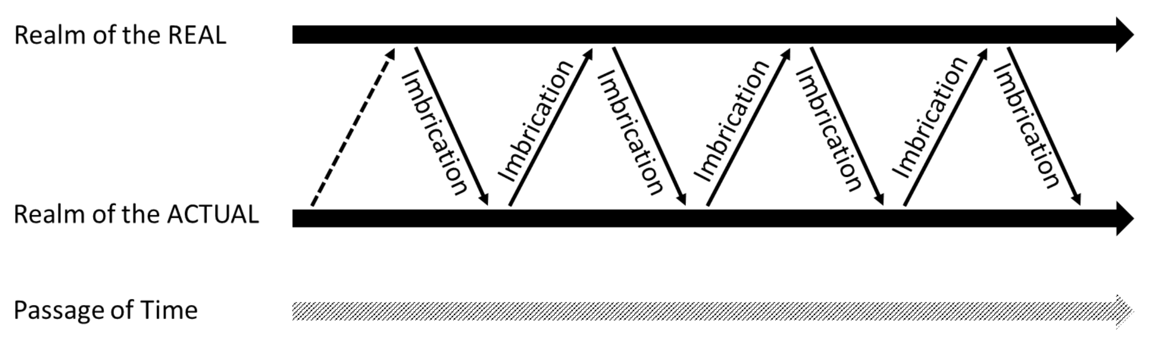
For example, in Shakespeare's *Romeo and Juliet*, the Capulets and Montagues, as feuding families, are each an autonomous social structure, with rules and associations. These structures are executed by the activities of its members where the openness of the system and its volatility are expressed by deaths, the subsequent tragic story line, and the two final deaths of the protagonists.

In the setting of a Smart City, the street, the neighbourhood, and the city are nested social structures that depend on the actions of their citizens to bring them to life. What therefore matters in social situations is context where the spatio-temporal relations of objects with each other may trigger, block, or modify actions through their own causal powers and liabilities (Sayer, 1999: 12-15). This underlines the fit of Relativism as an appropriate epistemology and case study as an appropriate methodology to examine the complexity of a phenomenon within its context.

Due to the complexity of open systems, CR rejects empiricism's constant conjunction model of causation and the simplified deductive/nomological model of reasoning, where cause and effect are distinct occurrences across time and space. It argues that the examination of causal structures, in open (social) systems, circles around two main complexities: 1) Structures have unenacted tendencies (i.e., where they have the power to act without performing the act) and thus prevent empirical observation. 2) Structures may act without an apparent empirical trace, i.e., through a neutralizing or counteracting force, or for the possibility that the observation remains unseen. Examples of the latter are invisible forces such as magnetic fields or radio waves or the simple absence of an observer (Grey and Willmott, 2005: 134). In a stratified ontology, that separates the *real* from the *actual* from the *empirical*, Juliet may still be a formidable actress even if she currently does not participate in a theatrical production – or, conversely, if she rehearses the part without anybody witnessing her performance. In addition, there may be more than one mechanism at work to produce a particular outcome (Easton, 2010: 124) – perhaps Juliet's greatness is reliant on the actor portraying Romeo as an ideal counterpart to channel Juliet's very best talent.

Once the concept of Sociomateriality is overlaid with CR, the realm of the *actual* represents the *"enactment of a particular set of activities that meld materiality with institutions, norms, discourses, and all their phenomena we typically define as social".* (Leonardi, 2012: 14). Figure 3.3 shows the influence of the *actual* domain onto the *real* through the process of imbrication over time-phased instantiations:

Figure 3.3 – Sociomateriality Framework Built on Foundation of Critical Realism



(Leonardi, 2013)

Through the passage of time, imbricated enactments modify the *real* as well as the *actual* realms in an ongoing exercise of the reconfiguration of reality. The sociomaterial constitutive entanglement in the *actual* realm influences, and is influenced by, the powers and tendencies that generate the entanglement. The value of Analytical Dualism is realized when slicing and analysing each instantiation of an imbrication along the passage of time. The next section describes how we can access and ultimately attempt to understand the top line of Figure 3.3, the realm of the *real*.

3.1.2.2 Critical Realism – epistemological assumptions

"Let causality not be a bare and invariant conjunction […] the mimetic reproduction of facts in thought, the object of which is to replace and save the trouble of new experience." (Mach, 1898: 192)

CR's **mediated knowledge** is expressed through the belief in the *intransitive* dimension (independent reality, the realm of the *real*) that we seek to explain by accessing the *transitive* dimension and mediated by social structures to which we belong. It positions the *transitive* dimension as an epistemological tool to gain insights into the *intransitive* dimension. The goal of CR is to find an **explanation** for causal mechanisms and to understand their social and cultural meanings rather than make precise predictions about future events (Wynn Jr and Williams, 2012: 793). It seeks to explain, through construction of a 'theory of understanding', <u>how and why</u> phenomena occur that were previously only poorly or imperfectly understood (Gregor, 2006: 624-625). The epistemological basis of CR renders it to be an ideal paradigmatic framework for attempting to answer research questions that begin with 'what caused…' or 'why is x occurring' (Easton, 2010: 123). The exploratory nature of this thesis is reflected in the circumstance that all its research questions begin with 'what'. The mechanisms extrapolated through 'what' lay the groundwork for subsequent 'why' questions that could be asked in a different study with a foray into CR's retrodictive stage. In this sense, asking 'what' provides insights into understanding why unintended consequences might emerge.

In contrast to an attempted value-free paradigm (Positivism) or value-laden advances, such as Constructivism, CR researchers strive to be value-aware with the understanding that the participant's perception is not reality but rather one of multiple windows that provide insights into a single reality (Healy and Perry, 2000: 123). The gate to such an accomplishment is inferential reasoning by linking facts (binding, uniting, grouping them together), observing contemplative premises, and judging whether these premises follow a rule. The key element in such reasoning is to understand why we see what we see – and whether the observed phenomenon is a coincidental association or suggests genuine causality (Hedström and Swedberg, 1996: 8-9).

Inferential reasoning aims to explain the contextual conditions of a **causal mechanism** that results in the empirical observation (Fletcher, 2017: 19) and theoretically ties back the manifest phenomena to the generative structure within the realm of the *real*, thereby expanding the constraints of the realm of the *empirical* (Grey and Willmott, 2005: 135). As summarized by Bygstad *et al.* (2016: 3): *"Mechanisms make things happen in the material world."*

The description of the generative *real* structure extends to actions and contextual conditions that are involved in the setting that prompted the observed phenomena (Wynn Jr and Williams, 2012: 789). The Humean theory of the actuality of causal laws can no longer apply when subjects, conditions, or forms of action are diverse and constantly changing in an open system (Bhaskar, 2013a: 94, 107). These forces are not nomological and explanations are asymmetrical so that empirical regularities would be a poor guide in establishing causality (Grey and Willmott, 2005: 134). Thus, causal laws are independent from patterns of events as well as from potential rationales of experimental activity. Within an open system, laws can only be universal if their interpretation is non-empirical (transfactual) and where activities of generative mechanisms and structures, as sets of internally related objects or practices, occur without constant conjunctions and act independently of sequences or patterns of events (Bhaskar, 2013a: 36, 33). So, in evading Nicod's criterion that one proposition confirms the existence of another, it cannot be putatively assumed that a preponderance of successful Shakespearean actor-graduates from one school *caused* Juliet's success if the actor graduated from the same school. For, *"theory is not an elliptical way of referring to experience, but a way of referring to hypothesized inner structures of the world, which experience can […] confirm or falsify"* (Bhaskar, 2013a: 149).

The identification of causal events is often constrained by the **unobservability of mechanisms** that prompts moving from direct observation of perceptual criteria to the observation of the mechanism's effects through causal criteria. This could be the case because the mechanism is not (yet) directly observable or measurable; although, an unobservable mechanism may become an observable one later through the passage of time. Bhaskar argues that *"[…] skilled men can come to have access to those enduring and active structures, normally hidden or present to men only in distorted form, that generate the actual phenomena of our world"* (2013a: 48-49). We can never be sure that we have identified a complete set of mechanisms, since unobservability makes accounting for completeness impossible, but the aim is to reach the core of an explanation through theoretical saturation (Bygstad *et al.*, 2016: 11). This can be achieved by 'weaving together' literature and data, which gives additional credence to the abductive and retroductive approach. Observability is thus not a requirement to locate and describe a mechanism, but its presence increases our confidence in the answer (Sayer, 1999: 12).

The evaluative cycle of the CR approach begins with a given set of experiences or results; it desires to answer what the world must be like for the phenomenon to occur. The researcher is attempting to uncover the anticipated existence of mechanisms which, if they existed and were enacted, could have produced these events (Sayer, 1992).

It does this through a double-reduction from the (assumed) rule or law to events and to experiences (Mingers *et al.*, 2013: 796) with the goal to identify mechanisms that connect *"chains of indeterminate events and complex interactions"* (Tan *et al.*, 2008: 45). This cycle is then repeated, by formulating a new proposition, if the successive steps do not lead to the inference of a satisfactory answer (Wuisman, 2005: 383-384). The reason(s) may be attributable to a genuine failure of the theory or a *pseudo-falsification loop* that can still lead to important insights such as: 1) Highlight that a theory is not yet sufficiently refined or developed to deal with anomalous counter-instances, 2) Clarify potential misrepresentations of encountered phenomena or choices in inappropriate observational theories or instruments, and 3) Extract a countervailing cause or interfering agent that had thus far not been anticipated (Bhaskar, 2013a: 151). The aim is to approach a theoretical propositional generalization that is different from the classic sense of 'generalization' such as across a population (Edwards *et al.*, 2014: 18).

This approach overlaps with Bhaskar's view regarding the explanation of an open-systemic event: causal analysis/resolution of the event (refers to step one above), theoretical re-description of the component causes as linking with step two, and finally retroduction via normic statements to possible causes of the components while eliminating alternative causes – in corresponding to step three above. All three steps in this sequence, together with their repetition in case of an unsatisfactory answer, are crucial to avoiding accidental generalizations that may be deductively explained or inductively confirmed (Bhaskar, 2013a: 115, 142).

CR accepts **multiple possible explanations,** which are common in open systems where the identification of exact causes and the elimination of all non-contributing factors of an apparent outcome is difficult. CR recognizes the possibility of multifinality, where similar initial conditions and mechanisms lead to varying end effects, and equifinality, where dissimilar conditions and mechanisms lead to similar end effects (Bhaskar, 2008: 133). The difficulty in establishing causality in process models, as opposed to variance models, does not allow a prediction, but rather an explanation of how processes unfold and what mechanisms move them along (Volkoff *et al.*, 2007: 843). Such an explanation can be highly valuable in a practical technology setting such as the implementation of new software in the endeavour to improve its effectiveness (Bygstad *et al.*, 2016: 12).

Where a simple answer to the causality question simply does not exist, CR provides a 'family of answers' that, imperfectly, covers several contingent contexts and different reflective participants (Pawson and Tilley, 1997: 152). The process of *"theoretical redescription and interpretation […] is about the steady unearthing of deeper levels of structures and mechanisms."* (Danermark *et al.*, 2002: 109-110). Ideally, such a 'family of answers', that describe generative mechanisms, is analytically established at an appropriate level of granularity (Mahoney, 2003) – a level that would provide sufficiently fine-grained explanations of causality in a practical mid-range theory (Hedström and Swedberg, 1996: 6).

All scientific knowledge is conditional (Hodgkinson and Rousseau, 2009: 540) and a highly complex system such as a Smart City is bound to contain layers upon layers of varying input conditions that can result in multi- or equifinal outputs. The multitude of input conditions based on network behaviour and feedback loops, coupled with the complexities of such as system, makes it impossible to predict the trajectory of an outcome of the system (Morell, 2018: 245-246).

CR also recognizes the possibility of a demi-regularity, or partial event regularity, where common physical or social structural elements and contextual factors at work lead to similar experiences. These elements and factors are produced by the occasional realization of a causal mechanism, with relatively enduring tendencies, in a bounded region of time and space (Lawson, 1997: 30-32). Even in the absence of a predictable match, demi-regularity still confirms the *possibility* of causality given a certain set of conditions and thereby furthers our understanding of the implicated mechanisms and structures.

Additionally, even if no satisfactory answer is found due to repeated pseudo-falsification loops, it is important to stick with the theory. If not, we might forego building out a theory that draws attention to findings that we would otherwise have never observed. Newton's law of universal gravitation is but one example that shows the theory's expansion from the planet's gravitational forces to their electro-magnetic properties that also influence their motion. In concert, unexplained phenomena or interferences – 'puzzles' in a Kuhnian sense – may provide a positive heuristic to contribute to a theory's 'protective belt' by modifying or adding auxiliary propositions (Lakatos, 1968: 167, 171, 173).

The answer for critical realists, whether an analysis appropriately suggests causation, lies in the concept of judgmental rationality, where claims about a facet of reality are introduced publicly with an invitation to comparatively evaluate the argument (Easton, 2010: 124). The perfect match between theory and reality is considered unlikely, especially when a new theory is first being introduced, and where the aim is to improve its coherence over time (Wynn Jr and Williams, 2012: 793). The selection of a theory, among alternative theories, lies in comparing their respective explanatory powers in the transitive dimension (Groff, 2004).

3.1.2.3 Critical Realism – methodological assumptions

"The point of theory is not to generalize, because many generalizations are widely known and rather dull. Instead, theory is a surprise machine"
(DiMaggio, 1995: 391)

In an **explication of events**, detailed aspects and the sequence of events are being identified, usually through the abstraction of experiences, that form the foundation for causal analysis (Wynn Jr and Williams, 2012: 797). This is done through the ontological assumption of a stratified reality (the *real*, the *actual*, and the *empirical*) and the epistemological assumption of mediated knowledge through the *transitive* dimension that aims to explain the *intransitive* dimension. It may take on the form of reinterpreting structural elements, causal factors, or by reframing events through the lens of existing theory (Wynn Jr and Williams, 2012: 798). In being consistent with most forms of realism, CR does not prescribe the specifics of this 'lens' since its epistemology is subjective and devoid of predefined or predetermined methodologies or criteria that provide a clear view onto reality (Van de Ven, 2007: 21). It is important to note that *events* in this sense are not only activities that occur within <u>systems</u>, but also extend to cognitions and emotions of <u>individuals</u> as they interpret and react to events (Langley, 1999: 693).

The analysis of events builds the basis for the **explication of structure and context**, which identifies and analytically resolves components of the structure that are causally relevant, spanning structures, actions, and contextual conditions in a particular setting, an undertaking that is at the centre of CR's purpose (Wynn Jr and Williams, 2012: 789, 798; Sayer, 1992: 95).

The aim of all scientific research is to explain the past, if not predict the future, based on observation of data. This is exercised through **deduction** (linking a fact or assumption to what follows) and **induction** (asking for justification for a belief or course of action), or **abduction** by suggesting that something *may be* (Minnameier, 2010: 240-242). The latter attempts to build the bridge from the *empirical* to the *real* by theoretically re-describing the observed object in an abstract sense with the aim to highlight the sequence that may have caused the pattern of events. This is done through a creative insight that would resolve an anomaly, which in this case would be *"a novel or unexpected phenomenon that cannot be explained or is poorly understood using existing knowledge."* (Sætre and Van de Ven, 2021: 684). The anomaly would be resolved, if it were true, via a conjectured (new) plausible alternative to the status quo that would explain the present phenomenon (Van de Ven, 2007: 22). Deductive, inductive, and abductive reasoning build upon each other in their quest to "understand the world" (Kay and King, 2020: 138).

Sætre and Van de Ven include retroductive steps in the abductive process; thereby, synonymizing retroduction and abduction – by observing the anomaly, confirming it, generating 'hunches' as to what may have caused the anomaly, and subsequently <u>evaluating these hunches</u> (2021: 686).

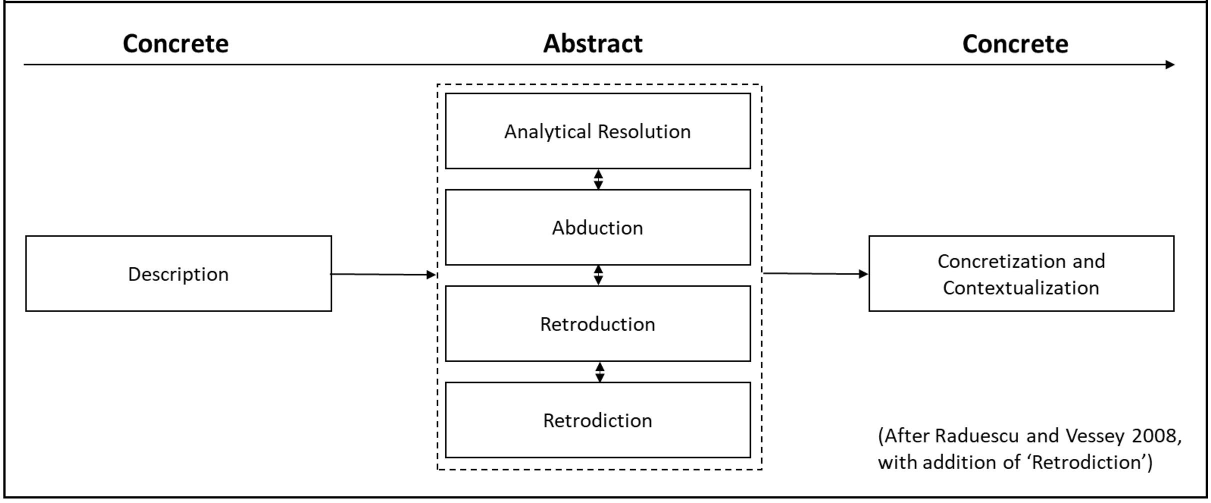
CR sees abduction and retroduction as distinct steps: abduction represents a creative 'maybe' phase that is followed by **retroduction** in finding the early evidence to support or disconfirm the abductive inference. Retroduction is a core method for attempting to portray causal mechanisms in CR, by describing how the world must be like for the observed mechanism to occur. We do this by working backwards, from contemporary structural configurations to the underlying generative mechanisms that produced them (Reed, 2011: 5). Retroduction is thus an inferential and iterative 'what if' application of explicated structural components across time-phased patterns to identify potential causal mechanisms – whether they are obvious or hidden (Edwards *et al.*, 2014: 17-18). Retroduction is largely a creative and intuitive process that takes interpreted beliefs of actors in the process into account since these actors apply their *transitive* interpretation to the *intransitive* mechanism(s) in question (Wynn Jr and Williams, 2012: 800), where the roots of such inspiration are often untraceable (Langley, 1999: 708).

During retroduction, alternate theoretical explanations of causal mechanisms are then triangulated through **empirical corroboration** with evidence in the case study (social structures, conditions, agency, and events) to ensure a sufficient approximation to reality as well as to provide convincing depth regarding the question of causality (Wynn Jr and Williams, 2012: 801). For each suspected causal explanation, the case study findings must be examined to establish consistency between the assumption and the finding. If there is consistency, the causal mechanisms achieve summative validity through surviving empirical *modus tollens* tests of 'if x then y' (Lee and Hubona, 2009: 246). This must occur with the understanding that *"there is no noncontingent certainty"* (McGrath, 1981: 180) but rather as close an approximation as possible towards the full understanding of causal mechanisms that is aided through a variety of data types, methods, and theoretical perspectives (Morse, 1991: 122).

CR offers the subsequent process of **retrodiction** to confirm findings of the retroductive phase and to add rigor to the explanation. During *retroduction*, we identify individual causal powers and mechanisms that may have produced events. These are then further investigated in the *retrodictive* phase to establish what mix of causal powers interacted in what way to produce any particular event (Elder-Vass, 2015: 2-3).

Figure 3.4 graphically portrays the progression from the description of a phenomenon, via methodological abstraction, to concretization and contextualization:

Figure 3.4 – Explanatory Framework from Description to Concretization and Contextualization



After describing a concrete event or situation, analytical resolution identifies and separates components of interest. The step of abduction suggests underlying reasons for why something may be the case through a reinterpretation of components of interest. Retroduction then tries to isolate the underlying mechanism(s) by anticipating what must have been present for the event or situation to occur. The abstractions are *"made 'real' within a Critical Realist frame by hypothesizing the necessary structures and mechanisms consistent with the previous abstraction."* (Danermark *et al.*, 2002: 109). Retrodiction further examines the mix of causal powers in the underlying mechanism(s) and the final stage of concretization and contextualization tests the applicability of proposed mechanisms to specific contexts and concrete situations. Since this step transcends from theory exploration to theory testing, it would often be conducted in a separate study (Dobson *et al.*, 2013: 969).

Bygstad *et al.* (2016: 8) add the dimension of affordances to CR data analysis since there are clear parallels between describing affordances, whether they are enabling or constraining (negative affordances), and linking them to generative mechanisms (Volkoff and Strong, 2013: 823-824). The model of Raduescu and Vessey (2008) is thereby expanded to include additional insights by probing for affordances as listed in Table 3.3:

Table 3.3 – Combination of Models: Raduescu and Vessey with Bygstad *et al.*

Concrete/Abstract	**Step**	**Addition or Change**
Concrete	Description	Description of events and issues in the case – as clusters of observations with varying degrees of granularity
Abstract	Analytical Resolution	Of key entities as objects of the case (organizational units, technology, relationships) – aggregated into structures (networks of entities with causal powers)
Abstract	Abduction/Theoretical Redescription	Abstraction of the case by exploring different theoretical perspectives and explanations/identify relevant theories to 'observe, describe, interpret and explain' within the frame of a new context
Abstract	Retroduction	Identification of immediate concrete outcomes using the technology
Abstract	Retroduction	Analysis of interplay of human and technical entities
Abstract	Retroduction	Identification of candidate affordances within the human/social and technical affordance (whether the affordance is actualized)
Abstract	Retroduction	Identification of stimulating and releasing conditions – including an analysis of affordance interaction and dependencies (temporal, structural, complementary) – mapping of affordances to higher-level mechanisms
Abstract	Retrodiction	Further triangulation of causal powers in generative mechanisms
Concrete	Concretization and Contextualization	The proposed mechanism should be treated as a candidate explanation – repeat data collection and

Table 3.3 – Combination of Models: Raduescu and Vessey with Bygstad *et al.*		
Concrete/Abstract	**Step**	**Addition or Change**
		analysis until closure is reached (mechanisms with strongest explanatory power)

In an example involving Smart City parking, one can assume the causal mechanism of enforced paid parking leads to greater availability of parking spaces. The Santander case study has produced empirical evidence, based on driver's perceptions, that finding a parking space is easier than it used to be. In addition, owners of businesses in the vicinity observe more space availability. All three data points in this example represent an 'if x then y' *modus tollens* argument and thereby corroborate the theoretical statement of 'paid parking = more availability'. The effect of increased availability of parking spaces is not necessarily caused by only one affordance, such as the enforcement of paid parking, but it can stem from a multitude of affordances in a complex relationship as well as from different structural levels underneath. Furthermore, these layers of structure and affordances can actualize over different time intervals (Volkoff and Strong, 2013: 824). It expands the statement of 'if x then y' into 'if x and / or v and / or w then y' such as in the example of 'paid parking *and measures to direct traffic elsewhere* = more availability'.

While this example is simple, it is not intended to minimize the complex interplay between social structures that produce outcomes (Porter, 1993: 53-54) and that will be examined in detail in the case study.

3.1.3 Overlay of Critical Realism, Sociomateriality, Analytical Dualism

This thesis suggests a view onto Sociomateriality through the lens of Critical Realism where CR's cornerstone of a stratified ontology is paramount.

It is proposed that Sociomateriality and CR are tightly connected at their epistemological roots. CR's *actual* domain corresponds with Sociomateriality's collective space of *practice* (Cook and Brown, 1999: 388), the *"human activity […] organized around shared practical understandings"* (Cetina *et al.*, 2005: 11), and a *"reality [that] is not given but performed through relations in practice"* (Cecez-Kecmanovic *et al.*, 2014: 811). CR's structural emergence, where entities exist in aggregated and non-aggregated summations of different levels is consistent with Sociomateriality's *constitutive entanglement* (Orlikowski, 2009: 12). This reality is coherent with CR's view of an open system with unstable empirical relationships (Bhaskar, 2013a: 64) that are found in highly adaptive technology platforms (Orlikowski, 2000: 406) with dynamic effects on people's work and lives (Orlikowski and Scott, 2008: 456).

Where CR starts to complement Sociomateriality is in its epistemological assumptions. CR's mediated knowledge separates what we want to explain (the *real*) from the environment to which we belong (the *actual*). It thereby opens a pathway to the explanation of causal mechanisms through inferential reasoning. This pathway is strengthened through CR's methodological assumptions: First, through the explication of events that starts to sequence events and experiences as a foundation for causal analysis (Wynn Jr and Williams, 2012: 797). Second, through the explication of structure and context that analytically resolves causally relevant components (Sayer, 1992: 95) as depicted in Figure 3.3.

Sociomateriality firmly incorporates the position of entanglement among structure, agency, humans, and non-humans (Scott and Orlikowski, 2014). While these entanglements, originally described by Orlikowski and Scott (2008) are inseparable, the *"actualization of affordances occurs over time"* (Volkoff and Strong, 2013: 824). **The recognition that individual instantiations occur over time allow for analytical separability.** This can be accomplished through Margaret Archer's theory of Analytical Dualism that regards 'time' as an analytical cycle between structure, action, and structural elaboration (Archer, 2010). It is in turn consistent with CR's retroductive portrayal of causal mechanisms across time-phased patterns (Edwards *et al.*, 2014: 17-18). The structural and agential linkages can be disentangled to view their internal causal dynamics through careful temporal ordering of their morphogenic sequences (Archer, 2010: 245-246).

The argument that Analytical Dualism, applied under the canopy of CR, is a value extension of Sociomateriality can only be empirically corroborated through a case study that provides sufficient depth in answering the 'causality question'. Sections 3.2 through 3.5 describe the selection, design, operationalization, and quality assessment techniques of such a case study.

3.2 Selection of case study method

"Scientifically significant generality […] is, for the most part, hidden encrusted in things, needing to be excavated in theoretical and practical labours of the most arduous kinds." (Bhaskar, 2009: 68)

The proximity to real-life situations is crucial when attempting to develop a nuanced view of reality since social science has not succeeded in generating epistemic and predictive context-independent theory and universals (Flyvbjerg, 2006: 4-7). The examination of the interplay between social theory and technology as applied by humans must therefore happen *in situ* by inspecting a real-life, contemporary bounded system – a case – that characterizes the object as well as the product of inquiry (Creswell, 2012: 97). It juxtaposes the natural complement to deductive research and aims to scrutinize the complexity of a phenomenon with all its aspects.

This can occur within and across a bounded system (case) to establish reasonable confidence in the understanding of underlying interactions between all facets of such a system (Eisenhardt and Graebner, 2007: 26).

CR studies are by default retrospective since in order to explain specific phenomena, they must have already occurred in reality (Wynn Jr and Williams, 2012: 804). Prior research projects have shown CR to be well suited for complex settings, such as in the field of technology, which is underlined by examples such as Volkoff *et al.* (2007), Williams and Karahanna (2013), Fox and Do (2013), and Purusottama and Kadarusman (2022). These authors applied CR to studies in the areas of technological embeddedness and organizational change, federated IT governance structures, Big Data, and Blockchain.

CR is appropriate for technology subjects that are relatively clearly delineated, such as within a Smart City (Easton, 2010: 123). It has shown to contribute to calls for improved theorizing between technical and social systems that are in a mutually constitutive relationship (Lee, 2004: 11). In Information Technology, the combination of the CR ontology with a relativist epistemology and in a case study research is well positioned to uncover causal mechanisms and generative contextual factors within socio-technical phenomena (Wynn Jr and Williams, 2012: 795).

3.2.1 Approach to case study

“Qualitative writers do not have recourse to the canonical statement of ‘results are statistically significant at p<0.05’” (Siggelkow, 2007: 20)

Three basic approaches to case study research were evaluated as to which would best lead to answering the research questions:

Yin equates the study of a single case with one experiment and introduces caution as to the analytical (theoretical) generalizability of findings by emphasizing multiple cases for increased robustness (2013: 21, 57). He suggests two to three instances for literal replication (where similar results are predicted) and four to six instances for theoretical replication (where contrasting results for anticipatable reasons are predicted). Yin guides the researcher to include existing theory or theoretical propositions into the initial design of the study and proposes that lessons learned could form working hypotheses (2013: 40-41). He goes beyond the argument of Siggelkow (2007: 21) who suggests that observations in case study research should be guided by initial hunches and frames of reference and Suddaby (2006: 634) who promotes a similar stance for Grounded Theory. Yin adopts a positivist-inclined view for hypotheses to be proven or disproven through subsequent findings within the case and advances theory testing by correlating the number of replications with the degree of certainty in the theoretical constructs (2013: 61). His methodological pathway through a case is well structured in that there should be a visible line from the research question(s) to study propositions and rival propositions, extending to the unit of analysis, with stated logic that connects data to propositions, and pre-defined criteria for interpreting findings (2013: 38).

Eisenhardt is concerned with inducing theory from case studies through an iterative process that recognizes the tentative nature of early constructs and accentuates the importance of not having preconceived theories and hypotheses from the outset (1989: 532, 536). She seeks to establish construct validity through an analysis process that toggles between data and theory and reveals definitions and concepts. These emerging constructs are then confirmed or disconfirmed through case evidence and are in turn solidified, revised, or discarded. Lastly, the emergent theoretical findings must be compared with the extant literature to strengthen internal validity and potential generalizability (1989: 542, 544). She highlights difficulties in generating complex theory with fewer than four cases and stresses the volume and complexity of data when dealing with more than ten cases. Eisenhardt's approach leans on a systematic and rigorous way of analysing qualitative data such as is championed by Miles and Huberman (2013: 9) and introduces a relativist angle. This is underscored by her method of an interactive comparison between qualitative data and a developing abstract theoretical understanding of the studied experience such as in Grounded Theory (Charmaz, 2014: 4). The approach is consistent with the tenet of CR that engages in intensive research by repeatedly moving between the concrete and the abstract; between particular empirical cases and general theory (Sayer, 1999: 23).

Stake advocates a disciplined and qualitative mode of inquiry into one or more cases – whether it is *intrinsic*, i.e. driven by the need to learn about a particular case, or *instrumental*, meaning as a tool to understand something else while still adhering to the concept that the *"first obligation is to understand the case"* (1995: 3-4). Stake pivots further towards the constructionist paradigm by avoiding situations to test hypotheses and letting dependent and independent variables develop in experiential and unexpected ways that result in multiple realities (1995: 41, 43). He champions naturalistic generalizations as *"conclusions arrived at through personal engagement in life's affairs or by vicarious experience"* and for the reader to *"add their own parts of the story"* while being *"assisted by associating generalizations that various actors or readers have reached together with a description of their experience"* (1995: 85-87). For multiple case studies, Stake emphasizes the need for vigorous understanding of each individual case in its ordinary environment and the subsequent arrangement into a 'quintain', as a *"collective target such as a program, phenomenon, or condition"*. He stresses the procedural and epistemological dilemma of the case-quintain boundary in whether everything in the particular is actually part of everything in the collective, thereby raising the generalizability question (2013: 24-26). He exercises caution regarding the latter since the *"power of case study is its attention to the local situation, not in how it represents other cases in general"* and rejects *"dwelling on causal explanations"* within the margins of the quintain (2013: 30).

Table 3.4 compares the case study approaches of Yin, Eisenhardt, and Stake across several key dimensions:

Table 3.4 – Comparison of Case Study Approaches Between Yin, Eisenhardt, and Stake

Dimension	Yin	Eisenhardt	Stake
Primary purpose	Theory testing	**Theory building**	Opportunity to learn and evaluate
Underlying ontology	Positivism	Interpretivism	Interpretivism
Analysis	Deductive	Inductive	Inductive
Theory and propositions	Brought forward in the beginning	**Build dynamically by toggling between data and constructs**	Deemphasized as they minimize interest in the situation/circumstance
Generalizability thoughts	Possible for theoretical concepts (analytical generalizability) – not in a statistical sense		"Case study seems a poor basis"
Literature review	**Prior to start**	Link back to literature during analysis to confirm or discard findings	"Each case is unique"
Suggested number of cases	2-3 for literal replication, 4-6 for theoretical replication	4-10 (less if there are embedded 'mini-cases')	One case is one case

Yin emphasizes for a case study to be informed by the prior review of the extant literature and Eisenhardt advocates theory building or elaboration which is a central tenet of this thesis. Eisenhardt also supports the dynamic toggle between data and constructs, which is the method employed in Chapter 7 (Discussion). These reasons support a combined use of the Yin and Eisenhardt methods.

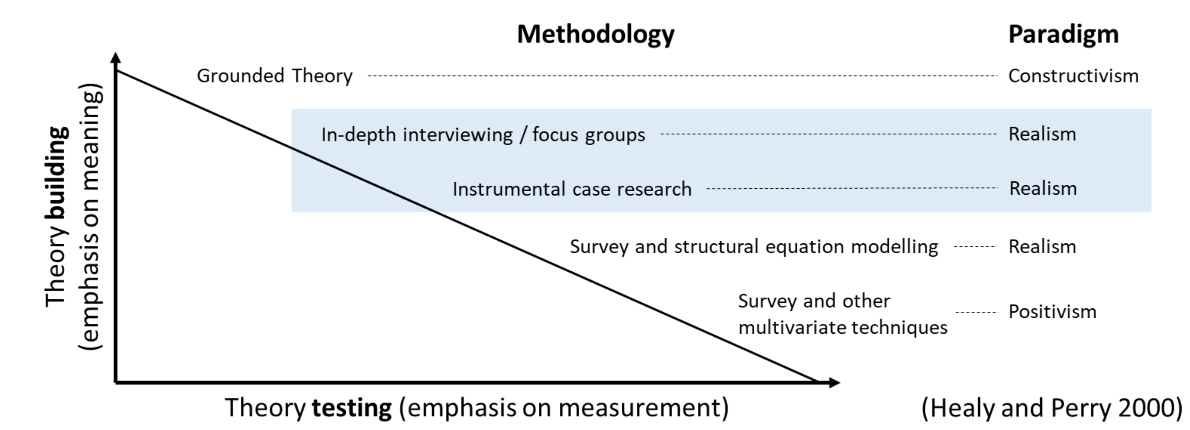
3.2.2 Elaboration of existing theory

“Theory is the currency of the scholarly realm…” (Hambrick, 2007)

Dimitriadis and Kamberelis speak of theory as *“abstract sets of assumptions and assertions used to interpret and sometimes to explain psychological, social, cultural, and historical processes. Theories are tools to help us think about things in new ways. Good theories are useful”* (2006: vii). This study reaches across several existing theories such as Affordance, Structuration, Sociomateriality, and Analytical Dualism and positions them in the realm of a rapidly changing technological environment. It attempts to generate, validate, and refine the interrelationships of this newly occurring phenomenon (Gioia and Pitre, 1990: 587) across constructs, propositions, arguments, and assumptions – as the four elements of a theory (Davis *et al.*, 2007: 481). Of particular importance here are the relationships which are embedded within and across these theoretical systems – and what results in their utility in what Bacharach defines as explanatory potential and predictive adequacy (1989: 507). The design of the study prompts for **theory exploration** of pre-existing conceptual ideas and preliminary models (Lee *et al.*, 1999: 164).

Healy and Perry (2000: 121) highlighted fitting methodologies across the continuum of theory building (elaboration) and theory testing as depicted in Figure 3.5:

Figure 3.5 – A representative range of methodologies and their related paradigms



The complexity of Realism makes this paradigm ideal for theory building and elaboration with associated methods of in-depth interviews, focus groups, and instrumental case research (Healy and Perry, 2000: 123).

Eckstein (2000: 119) states that *“case studies are valuable at all stages of the theory-building process”* and Walton (1992: 129) substantiates that *“case studies likely produce the best theories”*. Walton adds that *“a case empirically (re)-conceives an instantiation of something new or previously misapprehended, defines it theoretically through causal connections, and* *produces new ideas or interpretations"*. This bridges from Yin, who postulates the inclusion of existing theory or theoretical propositions (2013: 40-41), into Eisenhardt who puts forward an iterative process for theory building (1989: 532, 536) if the research question transposes existing theory into a different context (Eisenhardt and Graebner, 2007: 26). Elaborating on existing theory is the focus of this research by engaging with problems in the real world (Kilduff, 2006: 252) and the interlaced manifestation of theoretical knowledge with practice (Corley and Gioia, 2011: 23). The expansion of theory flexibly assesses connections within, and between, conceptual ideas and empirical data for relational fit where they unfold in a *"logic of discovery rather than only a logic of validation"* (Van Maanen *et al.*, 2007: 1146). It does this through simultaneous maximization of theory ('rigor') and practice ('relevance') in pursuit of achieving synergy (Gulati, 2007: 779). The existing theoretical constructs thereby undergo a translation process that results in a better understanding of how they apply in environments and contexts for which they were not originally conceived and fosters the development, expansion, and tightening of existing theoretical ideas (Fisher and Aguinis, 2017: 441-442).

What is offered in this translation process is a redirection of existing views on present phenomena (Conlon, 2002: 489) where such a qualitative study is expected to generate new ideas and perspectives as an appropriate tool for theory development (Easterby-Smith *et al.*, 2008: 485). The newly formed understanding presents an iterative, cyclical, non-linear, and exploratory theory-building process where tentative speculations about the structuring of processes are confirmed and disconfirmed (Gioia and Pitre, 1990: 588) in the quest to find enduring power mechanisms which act independently of the conditions that allowed us to identify them (Bhaskar, 2013a: 177).

There are several researchers who have successfully **elaborated on existing theory via case studies**:

Ross and Staw (1986) widened escalation theory by examining the organizational dynamics leading up to Vancouver, British Columbia's, world's fair in 1986 (Expo '86) and Perlow (1998) broadened the theory of (work-life) boundary control via a case study in the setting of a high-tech corporation. In the context of IT research, Hevner *et al.* propose a feedback loop of applied business contributions to the archival knowledge base within the domains of behavioural and design science (2004: 80-81). The work of Tripsas and Gavetti (2000) consists of a single in-depth inductive case study, following Yin, that highlights recursive relations between two entities over repeated interactions.

Paré and Elam (1997) utilized Eisenhardt's method to conduct three theory-building case studies in the field of IT and contributed to the discovery of new phenomena in the triad between system implementation context, tactics, and success. Edmondson *et al.* (2001) led a large-scale qualitative embedded multiple case study on operating room teamwork routine changes that employed a combined Eisenhardt and Yin case study approach. As a new theoretical contribution, it proposed a model of how teams and team leaders work together to learn and implement new behaviours and routines.

Volkoff *et al.* (2007) conducted one of the first single/embedded case studies in IT that relied on CR. By examining the implementation of an Enterprise Resource Planning (ERP) system, it gathered insights into changes to embedded routines, roles, and data within the system. Since one of CR's strengths is the application of the dimension of time, this longitudinal study compared different instantiations of the software and its use. The researchers were able to suggest reasons for alterations of routines and process sequencing, modifications to user's roles, and the positive effects of data availability and update frequency. The study then suggested the sequencing (imbrication) of embedded relationships between the organizational elements of routines, roles, and data/transactions (Volkoff *et al.*, 2007: 842-843).

Strong *et al.* (2014) further extended the linkage of affordances with actualizations through a longitudinal Grounded Theory study in the context of an Electronic Health Record (EHR) system. The case is made that the material is entangled with the social through the process of actualization as an intermediate between IT and actors.

3.3 Case study design – single/embedded

"A single case study must be able to stand on its own." (Easton, 2010: 119)

The aim is to select a single case that serves as a powerful example to illustrate the human-technology interaction in practice and that satisfies three important uses for case research: motivation, inspiration, and illustration (Siggelkow, 2007: 21): **Motivation** – in that one can obtain answers to the research questions regarding the intended and realized impact on human behaviour and the resulting consequences in an IoT Smart City parking environment. It is expected that these answers may subsequently lead to improvements in the design and human-technology interaction to recognize and address unintended, and to reduce unwanted, consequences. **Inspiration** – for the data to elaborate on the theory (-ies) that has (have) been brought forward. **Illustration** – for the framework to come to life in the presence of real data and for this data to suggest, conceivably tentative, causal relationships leading to unintended and unwanted consequences. While the study of one case can be equated to one experiment (Yin, 2013: 51), the statement transcends a literal comparison for *"while laboratory experiments isolate the phenomena from their context, case studies emphasize the rich, real-world context in which the phenomena occur"* (Eisenhardt and Graebner, 2007: 25).

The question of generalizability of theory in case study research is contested – with critics regarding case studies as *"a poor basis"* for theory building (Stake, 1995: 7), leading to *"fuzzy generalizations and propositions"* (Bassey, 1999: 14), or arguing the *"inability of case study to offer generalizable findings"* (Thomas, 2010: 576). Much of this criticism leads back to *Hume's truism* that a *"theory may never be scientifically generalized to a setting where it has not yet been empirically tested and confirmed."* (Lee and Baskerville, 2003: 240).

Bhaskar perceives Hume's truism as applicable to closed systems but not to open systems that undergo a constant conjunction of events (2013a: 3); as would be the case in a human-technical arrangement. In CR, generative mechanisms for empirically derived social science phenomena are equated to 'tendencies', which are not wholly predictive of the future, but nevertheless may offer a bridge from Hume to valuable future explanations of phenomena that are set in other organizations and contexts (Walsham, 1995: 79).

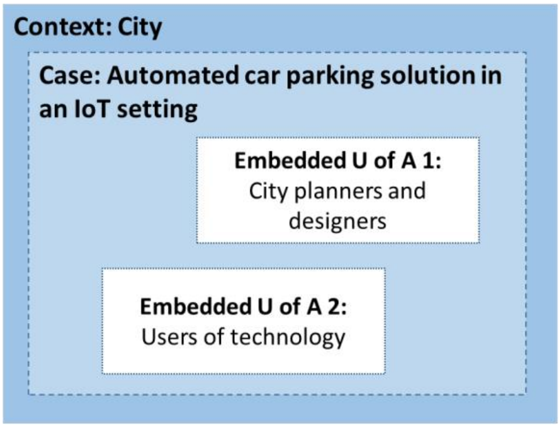
Others, such as Eisenhardt and Graebner, see a single case as conducive to elaborating on existing and complex theory *"…because the theory can be fitted exactly to the many details of a particular case…"*, with the anticipated result being more robust, parsimonious, and generalizable outcomes (2007: 30). Klein and Myers in one of their principles for interpretative field work in Information Systems research advocate the careful relation of particulars to abstract categories, unique instances, and ideas and concepts across multiple situations (1999: 75). Bygstad *et al.* argue that generalizability is dependent on the *"distinction between an affordance and its actualization"* analogous to a *"distinction between structure and function or form"* (2016: 12).

CR is especially useful for idiographic case studies since its methodology caters to *"detailed context-sensitive causal explanations of specific phenomena"* (Wynn Jr and Williams, 2012: 804) where Sayer sees no connection between the adequacy of a single case analysis – including the explanatory value of its causal relationships – with how many other such cases are being examined (1999: 21-22).

Regardless of the degree of epistemological certainty that one attributes to the ability of accepting the *general* based on the *particular*, the *general* will be strengthened by adding more instances of the *particular*. Adding cases increases analytical power (Eisenhardt and Graebner, 2007: 27), cross-case analysis contributes to building cumulative theory (Simons, 2009: 168), and multiple case studies provide greater scope for generalization (Rule and John, 2015: 9). While an increase in case replications is useful to gain additional context and a deeper understanding of structural mechanisms, it is different from the statistical (sampling-based) concept of generalizability with its aim to enhance validity or falsify a proposed mechanism (Wynn Jr and Williams, 2012: 805). The form of generalizability presented here is analytical and theoretical in nature (Yin, 2013: 21) by empirically assigning phenomena to theory (Lee and Baskerville, 2003: 237).

The single case in this study is divided into several subcomponents by following Yin's (2013: 50) single-case embedded design with multiple units of analysis as shown in Figure 3.6:

Figure 3.6 – Single-/Embedded Case Study with multiple Units of Analysis (U of A)



Based on Yin (2013: 50)

The city provides the context of the case in that it could be 'common' for an everyday situation, 'critical' with a set of circumstances within which the propositions are true, 'extreme' with deviations from theoretical norms, or 'revelatory' where phenomena were previously inaccessible to social science inquiry (Yin, 2013: 52). The context for the selection of this city is the setup, geography, climate, and other characteristics that distinguish it from other municipalities – it therefore resembles a **common case** according to Yin. The case itself is the ecosystem, in this instance an automated car parking solution in an IoT setting. The single case design permits depth in the analysis of how context and case interact; yet there are multiple units of analysis in a deeper refinement of the boundaries of the case. These embedded units of analysis are called out as discrete entities from the extended networks of which they are part of (Suchman, 2007: 283) and enable the application of **multiple-case logic** that allows for the identification of replication patterns and extensions of theoretical insights (Eisenhardt, 1991: 622). The two distinct entities here are city planners and designers (embedded unit of analysis 1) and technology system users (embedded unit of analysis 2).

In following this design, the test will be whether the theoretical propositions for unintended consequences can be replicated between the two subunits – the **entity that envisions** (plans/designs) and the **entity that consumes** (uses) the solution at hand. This resembles the dialectical concept of science in that there is taxonomic and explanatory knowledge: of what kinds of things there are versus how these things behave (Bhaskar, 2013a: 202). The degree of congruence between both is expected to strengthen the internal validity of the study (Yin, 2013: 46, 56).

3.4 Operationalization of the case study method

“Only if you are forced to state propositions will you move in the right direction.” (Yin, 2013: 30)

3.4.1 Selection of the city

Santander, in the state of Cantabria, Spain, was carefully chosen as a ‘common case’ to illustrate everyday situations (Yin, 2013: 52). Chapter 5, the case description, provides details about Santander’s geography, climate, history, its journey in becoming a Smart City, and other pertinent information for this study. It was necessary for this research to be conducted in a Smart City where an IoT-based parking solution has been in place for a sufficient window in time for practical use to generate unintended consequences (UCs). Only frequent everyday usage by residents and visitors alike, in various scenarios and over an extended period, provides fertile ground for UCs to emerge. This requirement restricted the number of target cities globally. However, Santander fulfils this prerequisite since its IoT-based parking system was implemented in 2012. The system has also undergone several enhancements over the years that make the analytical division into time-phased instantiations easier.

Santander also satisfies several characteristics that made it an ideal candidate for a ‘common case’ study: It is not ‘extreme’ in terms of geography, temperature, or climate; in addition, the implemented IoT solution is built around existing infrastructure. Unlike many newer Smart Cities in the Middle East or in Asia, Santander is in many aspects a typical mid-size and older European city. While several aspects of the municipality can be described as ‘ordinary’, this does not automatically assure transferability to other Smart Cities. It is possible that different climates, geographic setup, or age of a city may lead do different UCs.

It was helpful that Santander’s Smart City Program Management Office was very supportive of this research project and readily enabled access to city administration personnel as well as employees of the parking service provider (Dornier).

The data collection methods used for this study were in-depth expert interviews, brief on-location interviews of users (conducted just after they parked their cars), review of documents, observations, and photographic evidence, derived during an extended visit to the city.

In a preparatory step, the research questions were translated into case study questions as the basis for gathering primary data through interviews.

3.4.2 Operationalizing theoretical constructs: transformation of research questions into case study questions

While the case study ultimately attempts to answer the research questions, it needs an intermediary structure, a 'scaffolding', that relates high-level research questions with interconnected phenomena, acts, events, structure, and thoughts (Sutton and Staw, 1995: 378). The overall research question and its sub-questions is subsequently broken down into a lower-level question complex along different stakeholder groups:

What human technology interactions generate routes to unintended consequences in IoT parking systems within Smart Cities?

3.4.2.1 Case study questions to elicit unintended consequences and their evidence based on intent and design versus use

Is there a <u>complete match</u> between the intended and the actual experience for a given stakeholder group, i.e., are the three circles of the SBF (Human Agency, Material Agency, and Interpretive Schema) in an equilibrium? – this may suggest that there are no UCs. If yes, what may be the reason for this match?

Is there a <u>divergence</u> between the intended and the actual experience for a given stakeholder group? What may be the reason for this difference, i.e., is there a <u>preliminary assumption</u> of such a reason based on the opinion of a stakeholder? What arrow(s) of the SBF is (are) impacted by the stated opinion? How is (are) the arrow(s) impacted by the stated opinion? What is the apparent reason for this that is rooted in the <u>analysis of the data</u>? What arrow(s) of the SBF is (are) impacted by the analytically derived reason? How is (are) the arrow(s) impacted by the analytically derived reason? Is there a pattern in the reasons of incongruencies between the intended and the actual experience? Does the attribution of affected arrows highlight certain aspects of the pattern(s)? Is there a suggestion of causality in the event and arrow patterns? How do analytically derived causality patterns compare with the opinions of stakeholders, and can any insights be gained from this? What is the analytical reason for the pattern to be likely causal and not spurious to satisfy internal validity?

3.4.2.2 Case study questions to elicit intended and realized impact

What did each stakeholder group <u>intend</u> to happen (either to themselves or to other stakeholder groups) with regards to system/people behaviour and the role of Interpretive Schema? How would each stakeholder group know whether what was intended to happen did in fact happen, i.e., what are the assessment criteria? Were the assessment criteria effective as judged by each stakeholder group? If the criteria were not effective, why was that the case and how should they have been different? (this establishes a bridge to realized impact) What was (is) each stakeholder group's experience of what was (is) taking place? If there are defined measurement criteria, do the results support each stakeholder group's experience? If not, why not?

3.4.2.3 Case Study questions to elicit suggested actions to minimize unintended consequences and improve the design and interaction

What is the identified improvement opportunity? Does it relate to the IoT system design? Does it relate to the human-technology interaction? Does it suggest a change to an Interpretive Schema? Does the identified improvement opportunity surface more than once – i.e., is there a many-to-one relationship between the envisioned cause of undesired consequences and the perceived solution (i.e., an improvement opportunity)?

What is the presumed degree of, and reasons for, analytical and theoretical generalizability for the improvement opportunity to be beneficial outside of the boundaries of the case study?

The logical congruency of interconnectedness between research questions, phenomena, acts, events, structure and thoughts (Sutton and Staw, 1995: 378) will have to be evaluated as to their trustworthiness, credibility, confirmability, and data dependability (Yin, 2013: 45). This is important for two reasons: First, this exploratory case study elaborates on theory that, if deficiently constructed, were to have ripple-effects on subsequent work where rigor problems will likely surface (Gibbert *et al.*, 2008: 1). Second, the study is expected to be relevant to practitioners in a Smart City setting – yet, *"without rigor, relevance in management research cannot be claimed"* (Scandura and Williams, 2000: 1263).

These intermediary case study questions were then transposed into interview questions. The interviews were conducted using the interview questions listed in Section 3.4.3 below.

3.4.3 Data collection: expert interviews

The initial data collection occurred via seven semi-structured expert interviews in October 2019 where interviewees were selected based on their expertise in several areas of the Santander Smart City program. The individual interviews lasted between 45 and 90 minutes and were conducted mostly in Spanish (the researcher speaks Spanish fluently). The sessions took place in a face-to-face setting in Santander, were recorded, and subsequently translated from Spanish to English while being transcribed at the same time by the researcher. Prior to the start of each interview, an information sheet (in Spanish) was given to the interviewee that explained the aim of the study, requested permission for the interview to be recorded, highlighted the voluntary nature of providing answers, and referred to the interviewee's right to decline answers or end the interview at any point in time. The document also confirmed that all information obtained is treated confidentially. Each interview began after obtaining written consent from the informant.

Data derived from formal expert interviews were augmented through numerous informal conversations. The researcher's one-week visit to Santander was organized and hosted by the Santander Smart City Program Management Office and included activities such as a guided walkthrough through the inner-city parking area. These activities offered additional opportunities for data gathering, interpretation of photographs, and observations used in the analysis.

Figure 5.9 in Section 5.5 contains a map of the Santander parking stakeholders. For purposes of traceability, replicability, and to ascertain the representative mix of data, each actual quote of an interviewee was assigned an informant code. Table 3.5 contains the mapping of the informant code to the informant role and to the respective parking stakeholder group:

Table 3.5 – Mapping of Informant Code to Informant Role and Stakeholder Group

Informant Code	**Informant Role**	**Stakeholder Group**
C1	Santander Representative 1	City of Santander
C2	Santander Representative 2	Parking Service Provider (Dornier)
C3	Santander Representative 3	Smart Santander Administration
U1	University of Cantabria Representative 1	
U2	University of Cantabria Representative 2	Technology Provider (University)
U3	University of Cantabria Representative 3	
O1	Citizen Outreach Specialist	Associations/Interest Groups

The following 18 questions served as an interview guide whereby this structure still allowed a degree of freedom and adaptability in obtaining answers:

1) Who are the stakeholders interested in how parking is handled in Santander (and why)?
2) Who did you talk to in developing the intended solution?
3) Can you explain what system was in place before the automated parking program was implemented?
4) Can you give me details on the prior system's design? Ideally at a level of specificity where I could create a process flow.

5) What were your strategic objectives for the automated parking program for each stakeholder group? (i.e., citizens, designers, city administrators, etc.)
6) What behavioural changes did you envision for each stakeholder group? (i.e., citizens, designers, city administrators, etc.)
7) What mechanisms are in place to stop people from doing things that are not desired?
8) Can you list the requirements of the automated parking program?
9) Can you give me details of the new system's design and how this design fulfils the requirements?
10) How do the benefits of the program map to the design aspects of the system?
11) Given your earlier strategic objectives, what is different now? – for each stakeholder group and do you have examples? (i.e., citizens, designers, city administrators, etc.) – potentially follow-up with…
    … changes in user's behaviour – and why?
    … interaction with the automated system – and why?
    … pollution – and why?
    … traffic volumes – and why?
    … parking administration – and why?
    … city revenues – and why?
12) What about the system is working as expected and what is different? Why would this be important? Do you have any examples? – prompt for…
    … parking sensors and their effectiveness
    … IoT device website for looking-up the sensors
    … Smart Santander mobile application
    … display panels across the city that show available parking spaces
13) What are unintended consequences regarding people's behaviours, habits, or routines?
14) What are unintended consequences regarding procedures or processes?
15) Are there any other unintended consequences that we have not talked about yet?
16) Are there any formal design plans, user manuals, or other documents in place that I could review (for the current system as well as for the prior one)?
17) What methods would you recommend for me to get insights from actual users (citizens and visitors) of Santander? For example, a user or focus group.
18) If I have any more questions, can I talk to you again?

The seven expert interviews resulted in 368 minutes of recordings and a translated/transcribed count of 25,275 words.

3.4.4 Data collection: on-location interviews of users

In a second phase of data collection, 16 people using the parking solution were interviewed in Santander in March 2022. Their informant codes are R1 through R16, which are used in this thesis to mark individual quotes. These brief interviews, taking place when people left their cars after parking, lasted only minutes at a time. Due to the brevity of each interaction, no demographic information was captured unless the person volunteered such data while answering the queries. Each informant was asked four questions:

1) How often have you used the parking system in the past month? (deriving frequency of usage)
2) Can you give me an example of how you have used the system to make it work better for you? (inquiring about likes and benefits)
3) Can you give me an example of encountering an unexpected difficulty when using the system? (attempting to find out about dislikes or perceived disadvantages – or if the person has used the system in a way that was unexpected)
4) If you could, what would you change about the parking system? (probing again for dislikes or unexpected situations)

3.4.5 Data collection: review of documents, observations, and photographic evidence

The Santander Smart City Program Management Office, the faculty of the University of Santander, and the management team of the service provider (Dornier) made documents available to the researcher. These totalled 152 pages and were primarily used to construct the general case description in Chapter 5 and, more specifically, the process and data flow charts in Section 5.6. The artifacts also provided valuable details on the original project financial forecast and actual spend for the solution.

The collection of data was supplemented by 37 personal photographs that were taken during informal conversations with the Smart Santander Program Management Office guide. Outcomes of these conversations were captured through daily field notes and relevant photographic images were included in this thesis for better illustration.

3.4.6 Data analysis

UCs can occur when there is a disparity between the design (or intention) of a solution and its actual usage. The intended design or usage was derived in two ways:

For strategy-related problems, which are not attributable to a specific process but span across the entire parking solution, the designer's intentions were gathered from expert interviews and enhanced through the review of documents.

For process-related findings, which link back to a particular process or lower-level process steps, the intentions were described by constructing detailed parking process maps to capture the system's affordances (see Section 5.6).

By working systematically through the SBF, all activated arrows between Human Agency, Material Agency, and Interpretive Schema – for the design or the intention – were identified.

Once actual problems emerged from the interview data, all applicable arrows of the SBF were again identified. The UCs were then derived by comparing the realized impact with the intended impact whereby the SBF pathways (arrows) depict the interaction between expected use of the technology, its structures, and agents.

3.5 Quality assessment techniques within the case study

"Rule I: Always face your methodological problems squarely; or never turn your back on a Horned-Dilemma." (McGrath, 1981: 180)

Hammersley suggests a bridge between the central tenets of Critical Realism (CR) to a value proposition for assessing the quality of case studies (1992: 50-51). The causal mechanisms of the *real* domain within CR do not allow us to ever ascertain their validity completely since they are hidden. There are seemingly fitting explanations that always have the potential to be wrong as well as phenomena that are devoid of explanation since we cannot (yet) confidently assign them to corresponding mechanisms. What we can do is pursue an approximation based on *judgment* of plausibility, credibility, compatibility, and evidence – that goes beyond a reasonable doubt (Hammersley, 1992: 50-51).

Healy and Perry (2000: 122) defined a set of quality criteria for CR that is summarized in Table 3.6:

Table 3.6 – Quality criteria for case study research within the Realism paradigm

Element	**Description**	**Case study techniques**
Ontological appropriateness	Research problem deals with complex social science phenomena involving reflection.	Selection of research problem, for example, it is a 'how', 'why', or 'what' problem.

Table 3.6 – Quality criteria for case study research within the Realism paradigm		
Element	**Description**	**Case study techniques**
Ontological validity	Open ‘fuzzy boundary’ systems (Yin, 2013) involving generative mechanisms rather than direct cause-and-effect.	Theoretical and literal replication, in-depth questions, emphasis on ‘why’ issues, description of the context of the cases, internal validity.
Epistemology	Neither value-free nor value-laden – rather value-aware.	Multiple interviews, supporting evidence, broad questions before probes, triangulation. Self-description and awareness of own values. Published reports for peer review.
Methodological trustworthiness	The research can be audited.	Case study database, use in the report of relevant quotations and matrices that summarize data, and of descriptions of procedures like case selection and interview procedures = reliability.
Analytic generalization	Theory building rather than statistical generalization (theory testing).	Identify research issues before data collection, to formulate an interview protocol that will provide data for confirming or disconfirming theory. External validity through the specification of theoretical relationships, from which generalizations can be made.
Construct validity		Use of prior theory, case study database, triangulation.

Lincoln and Guba (1989) state the importance of trustworthiness, credibility, dependability, transferability, and confirmability for qualitative research and in doing so relate to Kidder and Judd’s (1986) guidance to conduct research that is grounded in reality, with identifiable relationships between variables, that is transferable, and conducted with rigor as well as quality.

Trustworthiness and grounding in reality –

This refers to the application of appropriate operational measures (Yin, 2013: 46) in that the study investigates what it claims to investigate in actuality (Gibbert *et al.*, 2008: 3). Eisenhardt and Graebner (2007: 25) advocate the comparison of data and theory in quick succession as mirrors of each other. This is accomplished within this study through constant comparison and triangulation of theory with data and an iteration towards theoretical constructs that closely fit the data (Eisenhardt, 1989: 541). This triangulation occurs at three different planes within a nomological network: 1) Observable properties or quantities to each other, 2) theoretical constructs to observables, and 3) different theoretical constructs to one another (Cronbach and Meehl, 1955: 11-12) whereby theoretical (intervening) constructs are often thinly conceptualized and thus difficult to validate (Davis *et al.*, 2007: 490).

Eisenhardt finds it crucial for a case study's credibility to understand the underlying theoretical dynamics as to why or why not emergent relationships hold (1989: 542). This is especially important in the exploratory theory building process as it logically strengthens the case study by suggesting causal relationships between variables and results as opposed to spurious links. It would bolster, as an example, the plausibility that 'a causes b', and not the reverse, and without an 'interference of c'. These variables represent a mere relationship (Cook and Campbell, 1979: 38) that is then transposed to the wider theoretical representation and touches upon questions of abstract inferences – where one infers that one event was caused by the earlier occurrence of another event (Yin, 2013: 47). This internal validity is anchored in a clear research framework that traces the link between 'a and b', while 'ruling out c' and through pattern matching in the data analysis phase where empirically observed patters are put side by side with their anticipated or predicted ones (Gibbert *et al.*, 2008: 3). Yin offers four specific questions to probe for these inferences: 1) Is the inference correct? 2) Have all rival explanations and possibilities been considered? 3) Is the evidence convergent? 4) Does it appear to be airtight? (Yin, 2013: 47).

Table 3.7 aligns Yin's questions to examine inferences with the case study questions described in Section 3.4.2:

Table 3.7 – Case Study Questions versus Yin's Examinations

Research Sub-Question	**Group of Case Study Questions**	**Map to Yin's Test Question**
Intended impact	Were measurement criteria effective?	1)
	If not, why not?	1) and 2)
	If not, how should they have been different?	2) and 3)
Realized impact	Do measurements support people's perception?	2)

Table 3.7 – Case Study Questions versus Yin's Examinations		
Research Sub-Question	**Group of Case Study Questions**	**Map to Yin's Test Question**
	If not, why not?	2) and 3)
Unintended consequences and potential pathways	Is there an unintended consequence (based on a preliminary assumption)?	1)
	Why or why not (based on stated preliminary assumption)?	1)
	Why or why not (based on first level data analysis)?	1) and 2)
	Where and why (based on second level pattern recognition)?	2) and 3) and 4)
	What is the congruency between pattern recognition and preliminary assumptions?	4)
How to minimize unintended consequences	What action can be taken and where (design, human-technology interaction, interpretive schema)	3) and 4)

The construction of the case study questions highlights a progressively descending probing into inference correctness, completion of alternate explanations, evidence convergence, and airtightness. The emergent theoretical findings must then be triangulated by adopting multiple perspectives (Gibbert *et al.*, 2008: 3) where Eisenhardt guides us to corroborate these findings with the extant literature to strengthen internal validity and generalizability – especially in the constrained scenario of only having one or a small number of cases (1989: 542, 544-545).

Another key factor in maintaining trustworthiness (internal validity) of a higher-order construct is for the researcher to consciously avoid for his or her preconceived notions (bias) to colour the work (Flyvbjerg, 2006: 17). Lastly, there is clear traceability in the chain of evidence that captures modification or summarization of raw data and resulting conclusions (Yin, 2013: 123-127).

Transferability –

The topic relates to the extent to which a study's findings are applicable beyond the work's confines as case studies typically deal with *"research situations where the number of variables of interest far outstrips the number of datapoints"* (Yin, 1984: 13). The main driver for transferability resides in the construction of the research questions – and whether they attempt to answer the 'how' or 'why' across causal connections (Yin, 2013: 48). Within CR, generative mechanisms are independently derived from the observer and therefore pose some questions about generalizability to comparable contexts. In the example of market dynamics, where buyers and sellers agree on a price that is acceptable to both, the unobservable generative mechanism of maximizing marginal utility becomes visible in practice. Moreover, the underlying mechanism is generalizable to situations within a similar context where each party in an efficient transaction aims for maximum gain while spending minimum resources (Bygstad *et al.*, 2016: 1).

This form of generalizability is methodologically entirely different from statistical generalization that infers extrapolations about a population from a statistically relevant sample (Gibbert *et al.*, 2008: 4). Since case studies provide for an opportunity to highlight theoretical concepts or principles, statistical generalization is inappropriate (Yin, 2013: 40, 48). Case studies do require a relevant sample that can ultimately be transferred and that was selected with this goal in mind (Cook and Campbell, 1979: 74). For this exploratory case study, theoretical (not random or stratified) sampling is appropriate. In leaning on Yin equating one case with one experiment (2013: 21, 57), an experiment is chosen for the likelihood that it will offer theoretical insight. We do not randomly sample laboratory experiments from a population of experiments and so a case should be selected on the merit of its potential for theoretical insight (Eisenhardt and Graebner, 2007: 27).

Dependability –

This is facilitated by having kept a case study protocol (i.e., a report of how the entire study was conducted) with the goal to minimize random errors and biases in the work by being able to repeat all operational steps in the study. This protocol is intended to trace how data collection and analysis brought forward results (Yin, 2013: 49). The researcher kept all artifacts that were collected or produced as part of the work, electronically, in an evidentiary database. These include interview recordings, transcripts, field notes (based on interviews, observations, and document analyses) and other case study objects. Another goal is for an independent observer to trace the chain of evidence that clearly captures the modification or summarization of any evidence from the initial data capture to the ultimate cast study conclusions (Yin, 2013: 123-127).

Wynn Jr and Williams (2012: 796) introduce a set of methodological principles for case study research in CR, applied in the setting of Information Systems research, that is summarized in Table 3.8:

Table 3.8 – Methodological Principles of Critical Realism (Evaluation Criteria)

Critical Realism Principle	**Evaluation Criteria**
<u>(1) Explication of Events</u> Identify and abstract the events being studied, usually *from experiences*, as a foundation for understanding what really happened in the underlying phenomena	• Thick description of case ‘story’ including actions and outcomes • An abstracted sequence of events (including the experiences of participants and observers)
<u>(2) Explication of Structure and Context</u> Identify components of social and physical structure, contextual environment, along with relationships among them. (Critically redescribed from actor’s viewpoint into theoretical perspective.)	• Description of the structural entities, constituent parts, and contextual conditions existing in the case • Identification of the relationships among the entities • Explication of changes to the structure • Description of the resulting emergent properties
<u>(3) Retroduction</u> Identify and elaborate on powers / tendencies of structure that may have interacted to generate explicated events.	• Identification of a set of plausible candidate causal mechanisms • Logical and analytical support for the existence of proposed mechanisms linking the structure to events
<u>(4) Empirical Corroboration</u> Ensure that proposed mechanisms have causal power and that they have better explanatory power than alternatives.	• Analytical validation of proposed mechanism based on case data • Assessment of explanatory power of each mechanism relative to alternative explanations • Selection of the mechanism(s) that offer(s) the *best explanation*

The next chapter deals with the initial testing of the SBF’s credibility through an evaluation of what Sætre and Van de Ven (2021) referred to as the ‘hunch’. This takes place by applying the framework to three thought experiments: a technology-enabled car park, an existing IT-related case study, and a manual car park.

4 The Sociotechnical Behavioural Framework in Thought Experiments

“The essence of theorizing is not discovering significant correlations, but finding a deeper explanation.” (Tan et al., 2008: 42)

The practical usability and early confirmation of the ‘hunch’ of the Sociotechnical Behavioural Framework (SBF) is simulated in the following thought experiments.

4.1 Technology-enabled car park thought experiment

The evaluation is summarized in Table 4.1 below. It assumes a technology-enabled car park where hypothetical misuses, design flaws, lack of adherence to norms, etc., cause for the intended equilibrium of the leaflets or arrows to shift out of balance and for unintended consequences (UCs) to arise.

The left column contains the reference as to which portion (leaflet) of the Venn diagram is activated. This is captured by shading the area in grey and annotated with symbols from mathematical set theory: M, I, H correspond to Material Agency, Interpretive Schema, and Human Agency. (∪) expresses a union with objects that belong to one or the other set. (∩) expresses an intersection with objects that belong to both sets. (') expresses a complement containing the objects that do not belong to this set. In taking the first row as an example: (M ∪ I)' ∩ H. It signifies that M and I are a union (∪) and refers to its complement ('); thereby, excluding everything that belongs to M and I. This intersects (∩) with H, meaning that only H is included since all of M and I is left out.

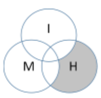
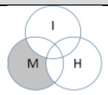
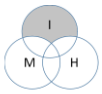
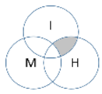
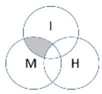
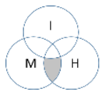
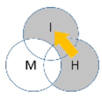
Table 4.1 – Technology-Enabled Car Park Thought Experiment	
(M ∪ I)' ∩ H 	**Human Agency (by itself)** This space represents basic human abilities (effectivities) to interact with the environment, which at this elementary level is devoid of Interpretive Schema such as language or rules. Examples of this would be a person’s ability to speak, see, to exercise digital dexterity, possess curiosity, or the desire and willingness to interact with humans or machines. In its basic form, it would be for the human to desire to use the car park.
(H ∪ I)' ∩ M	**Material Agency (by itself)**

Table 4.1 – Technology-Enabled Car Park Thought Experiment	
	With regards to the theory of affordances and constraints, this leaflet represents possibilities for action that material objects afford as natural object behaviours obeying physical laws and constraints. These affordances, and in their inverted form constraints, are real, objective, neutral, and devoid of value and meaning. Examples: The affordance of a parking space to hold a motor vehicle, the capability of a parking system to accept payment, the physical constraint of available parking spaces, or the need for access and connectivity to process a transaction.
(H ∪ M)' ∩ I 	**Interpretive Schema (by itself)** In leaning on normative theory, the area is defined as norms, rules, and standards that are present even in the absence of human (social) or material (technical) interpretation. It is the existence of universally predictable behaviour that is not reflected in the design of a material object nor subjected to whether a human executes such a process as intended or not. Because these norms do not intersect with Human nor Material Agency, they are unmanifested and unenacted – thereby, instinctive, tacit, and encoded. Examples of these are the basic desire for self-preservation, fight or flight, fear, happiness, care for others, etc.
I ∩ H 	**Intersect between Interpretive Schema and Human Agency (Social Norms)** This is the socially acceptable behaviour that an individual is expected to follow as part of a group, community, or culture for social effectivities. It is anticipated that car park customers will pay for using the service, will stay within the confines of their parking stall, will not damage other user's, the city's, or the operator's property, and will generally act in a way that enables everybody else's uninhibited use of the facility.
I ∩ M 	**Intersect between Interpretive Schema and Material Agency (Technical Norms)** This entails all physical and logical confines in which the technical solution is designed to operate within – for example the design and technical specifications, user manual, or operating procedure. In the case of a car

<table>
<tr><th colspan="2">Table 4.1 – Technology-Enabled Car Park Thought Experiment</th></tr>
<tr><td></td><td>park, the technical specification may define that physical access to the facility will be granted upon payment or that egress is prevented in case of an expired parking ticket.</td></tr>
<tr><td>H ∩ M
</td><td>Intersect between Human Agency and Material Agency

Absent a framework for interpretation, this space addresses basic emotional (not cognitive) user reactions that could surface through emotions such as fear or anger, relating to Material Agency, without the interpretative step of human rationalization of such emotions. Within a car park, the unexpected behaviour of equipment could cause the user to become frightened or the perception of being treated unfairly by the system may cause a person to become angry, which in turn could prompt acts of wilful destruction.</td></tr>
<tr><td>H ∪ I
</td><td>Human Agency influencing Interpretive Schema (Arrow 1)

This relationship reflects the formal or informal (social) influence on norms when engaging with a technical solution. The effects of this engagement, and the desired or realized outcomes, are likely divergent for different stakeholder groups – for example, city administrators and solution designers may actively promote an automated parking system, whereby users may passively resist a (perceived) overpriced, complicated or insecure solution, thus countering widespread adoption.

In the context of an automated parking solution, there are 12 (3 x 2 x 2) examples of how different stakeholder groups actively or passively influence the formation or modification of formal or social norms as a response to their experience of using the system:

<table>
<tr><th rowspan="2">Stakeholder Group (3)</th><th colspan="2">Norms (2)</th></tr>
<tr><th>Formal</th><th>Social</th></tr>
<tr><td>Users</td><td colspan="2" rowspan="3">Engagement: Active or Passive (2)</td></tr>
<tr><td>City Administrators</td></tr>
<tr><td>Solution Designers</td></tr>
</table>
</td></tr>
</table>

Table 4.1 – Technology-Enabled Car Park Thought Experiment	
	Stakeholder Group: Users / Norms: Formal / Engagement: Active – through votes, referendums, petitions, or other organized forms of electing officials or establishing and altering public policy Stakeholder Group: Users / Norms: Formal / Engagement: Passive – by reinforcing an existing framework through faithful usage or prompting modifications to the framework by either not using it or using it in a way that is inconsistent with the current norms, rules, laws, or standards Stakeholder Group: Users / Norms: Social / Engagement: Active – establish or reinforce (new) social trends by deciding when to use or not to use a system, in what fashion, with possible preferences based on day or time (e. g. during rush hour) or environmental conditions (e.g., traffic congestion, rain) Stakeholder Group: Users / Norms: Social / Engagement: Passive – conceivably, new habitual practices could emerge or be reinforced inadvertently without conscious choices, that are rooted in outside influences; much like fashion, once a sufficient number of people follow a trend, a new social practice could be formed Stakeholder Group: City Administrators / Norms: Formal / Engagement: Active – through the mandate of providing (better) parking solutions to a municipalities' citizens and visitors Stakeholder Group: City Administrators / Norms: Formal / Engagement: Passive – by prompting modifications or cancellations of ordinances or rules if they are obsolete or no longer deemed applicable Stakeholder Group: City Administrators / Norms: Social / Engagement: Active – by actively promoting automated parking solutions through advertising or other programs of communication or endorsement Stakeholder Group: City Administrators / Norms: Social / Engagement: Passive – if non-deliberate (accidental) activities by city administrators exert influence over adoption; for example, if the mayor, as a prominent city official, is observed using the car park Stakeholder Group: Solution Designers / Norms: Formal / Engagement: Active – emerging industry practices for designing and developing

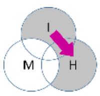
<table>
<tr><th colspan="2">Table 4.1 – Technology-Enabled Car Park Thought Experiment</th></tr>
<tr><td></td><td>
applications may become institutionalized, for example the migration from traditional ‘waterfall’ system development to the more recent ‘agile’ methodology
Stakeholder Group: Solution Designers / Norms: Formal / Engagement: Passive – the modus operandi that is anchored in a designer’s firm’s business practices may alter overarching standards over time, for example ad-hoc or rapid development, leading to potential quality problems, could as a result tighten universal standards of excellence
Stakeholder Group: Solution Designers / Norms: Social / Engagement: Active – like city administrators, companies who design and build parking solutions have a viable interest in their widespread usage; it is conceivable that this commercial interest is being advanced through advertising and promotion of the business
Stakeholder Group: Solution Designers / Norms: Social / Engagement: Passive – individuals who build solutions would also often be using them; and as consumers of the technology, they are likely to have unique perspectives and interpretations, which could affect designs, rules, or standards
</td></tr>
<tr><td>I ∪ H

</td><td>
Interpretive Schema influencing Human Agency (Arrow 2)
As a counter-flow to Arrow 1, formal or informal (social) norms influence Human Agency, i.e., effectivities, without impacting any object affordances in the engagement with a technical solution. There are again 12 possible constellations (3 x 2 x 2):
<table>
<tr><th rowspan="2">Stakeholder Group (3)</th><th colspan="2">Norms (2)</th></tr>
<tr><th>Formal</th><th>Social</th></tr>
<tr><td>Users</td><td colspan="2" rowspan="3">Engagement: Active or Passive (2)</td></tr>
<tr><td>City Administrators</td></tr>
<tr><td>Solution Designers</td></tr>
</table>
</td></tr>
</table>

Table 4.1 – Technology-Enabled Car Park Thought Experiment	
	Stakeholder Group: Users / Norms: Formal / Engagement: Active – by adhering, or not adhering to, established laws, public policies, and (parking) rules Stakeholder Group: Users / Norms: Formal / Engagement: Passive – by providing guidance to users on what should or should not be done, which in turn may prompt changes to the framework Stakeholder Group: Users / Norms: Social / Engagement: Active – adopting existing or new social trends that previously spread through growing adherence to these trends Stakeholder Group: Users / Norms: Social / Engagement: Passive – much like in the 'Active scenario', new trends could be picked up by an increasing number of people even if they emerged inadvertently Stakeholder Group: City Administrators / Norms: Formal / Engagement: Active – the availability of more (and better) parking solutions would prompt citizens and visitors to use them more frequently Stakeholder Group: City Administrators / Norms: Formal / Engagement: Passive – by enforcing, or not enforcing, ordinances or rules that would subsequently render them obsolete or no longer applicable Stakeholder Group: City Administrators / Norms: Social / Engagement: Active – through the reinforcement of successful advertising or promotional campaigns Stakeholder Group: City Administrators / Norms: Social / Engagement: Passive – new trends may be stablished if city officials, for example the mayor, is seen using the car park Stakeholder Group: Solution Designers / Norms: Formal / Engagement: Active – an increasing number of application designers and developers may be adopting emerging new industry practices – for example the 'agile' methodology Stakeholder Group: Solution Designers / Norms: Formal / Engagement: Passive – new standards for excellence may be ubiquitously adopted, which recursively propagates these new standards

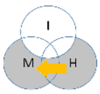
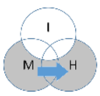
Table 4.1 – Technology-Enabled Car Park Thought Experiment	
	Stakeholder Group: Solution Designers / Norms: Social / Engagement: Active – advertising and promotional activities by designers may in turn contribute to spreading the usage of these solutions Stakeholder Group: Solution Designers / Norms: Social / Engagement: Passive – new or altered rules and standards would subsequently be picked up by users of the technology
H ∪ M 	**Human Agency influencing Material Agency (Arrow 3)** Human action directed at objects without societal rule moderation could occur in the presence of basic emotions such as fear, anger, or delight. For example, the unexpected lowering of a barrier may cause a driver to become frightened and suddenly forge ahead, causing damage to the barrier. Likewise, the perception of being treated unfairly by the system, e.g., by being overcharged or by not being assigned a parking space that is obviously available, may prompt an angry response that could give rise to acts of vandalism. Conversely, something that positively surprises a user could prompt a welcoming response resulting in more frequent use of the parking facilities. Another example in this space could be the utilization of the material affordance in a non-modal design way – by using the car park as a campground, by double-parking and preventing another user from leaving, or by parking in an unassigned space.
M ∪ H 	**Material Agency influencing Human Agency (Arrow 4)** The behaviour of a system, whether expected or unexpected – determined by design limitations or oversights, actual functionality versus design mismatches, equipment malfunctioning, etc. – could enable humans to seek and gain advantages outside established norms, rules, laws, and standards. The system thus provides alternative affordances than are not accounted for in the original design. There are different means of how people can work around the system and Chapter 6 (Case findings and analysis) provides examples of these. One possibility in this thought experiment is the control mechanism for opening

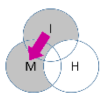
Table 4.1 – Technology-Enabled Car Park Thought Experiment	
	or lowering the barrier at the entrance or exit after payment is issued or proof of payment is confirmed. By blocking the photo-electric beam, it may be possible to pay only once, yet have several cars proceed into (or out of) the facility while the barrier remains open. Or, in a car park with license plate recognition, a driver may be able to alter or obstruct the registration and thus avoid payment. Another possible issue with design mismatch or equipment malfunctioning may be for the barrier arm to be broken where potentially only a short stub remains. The system may subsequently act as if it raises or closes the arm, according to its design, but without providing a workable barrier. The absence of the arm may invite cars to drive into the facility without paying where other non-modal downstream consequences are likely to occur – for example an overstated count of parking spaces that signals availability where there is none.
I ∪ M 	**Interpretive Schema influencing Material Agency (Arrow 5)** The interpretive framework would influence technology, meaning the capabilities of the machine, directly or indirectly – at a macro or micro level: From a <u>macro level</u> perspective, the ecosystem that a company operates in determines the path for potentially several overarching rulesets that organizations are expected to comply with. For example, a publicly traded company in the United States is subject to regulations specified in the Sarbanes-Oxley Act of 2002 (SOX). If a company is certified by the International Organization for Standardization (ISO), it agrees to adhere to a specific code of standards. Once a company processes credit card information, its customers may demand for it to follow the Payment Card Industry Data Security Standard (PCI DSS). Another example is Europe’s General Data Protection Regulation (GDPR). At a <u>micro level</u>, relating to the design and construction of technical solutions, there is a variety of standards that could apply, e.g. building standards, Restriction of Hazardous Substances Directive (RoHS) – through an order by the European Union to curb the use of certain hazardous substances in electrical and electronic equipment, or Wireless Personal

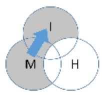
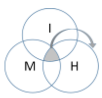
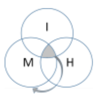
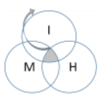
Table 4.1 – Technology-Enabled Car Park Thought Experiment	
	Area Networks (WPAN) – through the Institute of Electrical and Electronics Engineers (IEEE) standard IEEE 802.15 that defines the operation of low-rate wireless personal area networks.
M ∪ I 	**Material Agency influencing Interpretive Schema (Arrow 6)** Conversely, the advances of new technical capabilities prompt further enablement or restriction in their interpretation or application. At a <u>macro level</u>, the pervasive availability of personal information gave rise to the European General Data Protection Regulation (GDPR) that establishes territorial scope, penalties, consent, and other extensive rights awarded to data subjects. An example at the <u>micro level</u> would be new design guidelines in the security realm to prevent unauthorized use of information – for instance by preventing the placement of malware through enhanced security protocols such as ‘secure boot’ and more elaborate encryption methodologies. In the case of a car park, the existence of a date/time-stamped record of when a vehicle entered or exited a building or parking lot, particularly if this is coupled with the presence of a picture or video image of the driver, prompts for a clear rule set as to what can be done with this data, for what purpose, and who has the right to access it in the first place.
(H ∩ M) ∩ I   	**Intersect between Human Agency, Material Agency, and Interpretive Schema influencing in turn Human Agency, Material Agency, and Interpretive Schema (Arrows 7, 8, and 9)** This section signifies the sociomaterial constitutively entangled ecosystem where all three circles of the Venn diagram are in simultaneous interaction with each other – across human emotional responses, rational design decisions, and a normative or social interpretive context. Over time, enacted structures have influenced Human Agency, Material Agency, and Interpretive Schema that led from simple manual and ticket-based car parks to the development and adoption of IoT-enabled parking solutions. Ideally, such technological transformation should happen in alignment with people’s interests and social values. In reality, competing

Table 4.1 – Technology-Enabled Car Park Thought Experiment	
	forces will likely cause misalignments and divergence in routines, norms, and technology affordances relative to intent. The aim of the framework is to assess how the system is working in practice and to suggest refinements to the system's design that will address these distortions and divergences.

This simulated thought experiment shows that plausible simple situations, exchanges, and connections between Human Agency, Material Agency, and Interpretive Schema can be attributed to pathways between the three circles of the framework as expressed by arrows 1 through 9. The next section transfers the SBF onto a previously published case study by Eaton *et al.* (2015) to further explore its applicability in the context of human-technology interaction.

4.2 Overlay of the SBF onto the Eaton *et al.* case study

"Scientifically significant generality does not lie on the face of the world, but in the hidden essences of things" (Archer et al., 2013: 217)

This thought experiment is another elementary test of the SBF by applying its concepts onto two themes that emerged in the Eaton *et al.* (2015) case study: the interaction and resulting conflicts between third-party developers and a large technology company (Apple). This exercise in validating the framework assigns each step of an action or reaction, as described in the case study, to one of the framework's nine arrows that signify the interaction between Human Agency, Material Agency, and Interpretive Schema. This case study is particularly relevant as an example since it embodies a single embedded case study (with multiple units of analysis), following Yin, in combination with an Eisenhardt-oriented inductive theory elaboration. As described in Section 3.2, this thesis also employs the Yin and Eisenhardt approach via a single embedded case study.

Eaton *et al.* set out to augment two existing theoretical constructs: Pickering's argument that Human Agency and Material Agency reciprocally influence each other through a dialectic of resistance and accommodation. In this, Pickering likens the human adjustment to Material Agency with 'tuning'; such as one would perform on a radio or a machine (1993: 565, 567, 576). The 'tuned entity' in turn behaves differently, which triggers a change to Human Agency, and a subsequent new cycle of 'tuning the machine' and so forth. The second construct elaboration occurs with Barrett and Davidson's expansion of 'tuning' in the context of digital innovation in the global service industry (2008: 1). Eaton *et al.* examined 4,664 blog articles on Apple's iOS service system where "service" is defined as *"the application of specialized* *competences, such as knowledge and skills, through deeds, processes, and performances for the benefit of an entity"* (Vargo and Lusch, 2004: 2). The case study extracts the formation and influence of boundary resources on 'tuning' of the service system. Boundary resources are software tools (development kits, application program interfaces) and regulations meant to level conflicting priorities between a powerful platform owner (in this case Apple) and distributed application developers who attempt to 'tune' the technical platform. It is through these 'arm's length' resources that a firm controls its own infrastructure while it allows diverse actors to participate in and contribute to the service system – in a delicate balance of exercising constraint while promoting generativity (Ghazawneh and Henfridsson, 2013: 2).

The case study relates to this thesis for four reasons: First, it successfully applied the combined Yin and Eisenhardt approach – drawing upon Yin's guidance for inclusion of existing theory ('tuning') and complementing it with Eisenhardt's process of advancing an existing construct by toggling between data and theory. The case study also draws upon Eisenhardt to confirm the altered theoretical proposition by collecting case evidence. Second, the Eaton *et al.* case study, among other contributions, advances existing theory in that it challenges the dialectic relationship between actor and artifact and amplifies the complex, mutually constitutive, and networked sociomaterial nature of a common service system (Eaton *et al.*, 2015: 237). Third, the findings of the case study support the underlying premise of the SBF in outlining the entanglement of humans, machines, and interpretive schema. Lastly, it represents a partial early retroductive validation of the SBF that was abductively developed as a framework.

Two subjects that emerged in the case study were chosen for the practice to analytically superimpose the Sociotechnical Behavioural Framework: 1) conflict in the distribution of applications written in Apple's native mobile Operating System (iOS), and 2) the negotiation of content control between third-party developers and Apple. The exercise attempts to assign each action and reaction by Apple and the developer community to one of the nine arrows of the framework that convey the interaction between Interpretive Schema (I), Human Agency (H), and Material Agency (M).

Table 4.2 captures the first subject surrounding the distribution, installation, and execution of apps written in Apple's native iOS Operating System. These apps are an ongoing source of struggle between Apple and the members of the development community due to each having conflicting goals (Eaton *et al.*, 2015: 224):

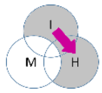
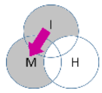
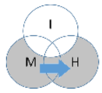
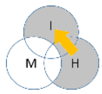
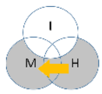
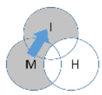
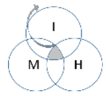
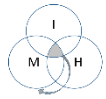
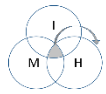
Table 4.2 – Distribution of apps written in Apple's iOS Operating System		
Action	**Interpretation**	**Arrow**
Apple informs the iOS community of the rule that the iPhone will not be open to native apps written by third-party developers, citing security concerns	Apple imposes a formal rule (Interpretive Schema) on its developer community that restricts their ability to perform an action and likely also affects their personal routines (Human Agency)	 (#2)
Apple designs the boundary resource of the iOS kernel to resist installing code by developers who are not affiliated with Apple Inc.	The company changes the iOS kernel design (Interpretive Schema) to alter the system's affordance of allowing to install third-party developer's code (Material Agency)	 (#5)
The iOS kernel prevents third-party (non-Apple affiliates) from developing applications	The changed affordance (Material Agency) now physically inhibits the third-party developer's ability to write applications (Human Agency)	 (#4)
Developers communicate their strong disagreement to Apple, via blog entries and dispute incident filings, causing the company to evaluate their current rules	Developers make their dispositions (Human Agency) known to the company to change the newly imposed rule and iOS kernel design change (Interpretive Schema)	 (#1)
Third-party developers find a way to hack into the iOS kernel, thereby forcing the ability to place their applications onto the iPhone	Developers expand their skills (Human Agency) to be able to hack into the iOS kernel (Material Agency)	 (#3)
The newly created affordance of placing third-party code onto the iPhone poses a deviation from the established standard and creates a security risk	The hacked code of the iOS kernel (Material Agency) represents an altered affordance in that it no longer conforms with its design (Interpretive Schema)	 (#6)

Table 4.2 – Distribution of apps written in Apple's iOS Operating System		
Action	**Interpretation**	**Arrow**
Apple responds by changing the technical design of the boundary resource to close the loophole of open-access iPhones	The interplay of all three circles (Human Agency, Material Agency, Interpretive Schema) prompts a change to the technical design (Interpretive Schema)	 (#9)
Apple translates the modified design into a new technical constraint within the iOS kernel	The same interplay transposes the changed design onto the system (Material Agency)	 (#8)
The non-Apple developer community is (for now) forced to accommodate the change in the system	The same interplay forces a change of abilities and personal routines (Human Agency) onto the developer community	 (#7)

As outlined in the case study, the cycle then begins anew in continued dealings of resistance and accommodation between Apple and third-party developers in which the latter did not accept the enacted restriction by the company of 'closed' iPhones. The developer community found a way to circumvent the procedural and technical limitations through what subsequently became known as 'jailbreaking'. This triggered another cycle of firmware-updates to try and prevent the new practice. Steve Jobs, Apple's Chief Executive Officer at the time, commented on the *"cat and mouse game"* between the company and hackers: *"people will try to break in, and it's our job to stop them breaking in"* (Hansell, 2007). The practice continued as has been observed by several practitioners (Klosowski, 2015).

This experiment illustrates the successful assignment of time-bound individual instantiations of accommodation and resistance, between Apple on one side and third-party developers on the other side, to each of the nine interactions (arrows) between the three circles of the Venn diagram. It highlights that even in the entangled interplay between Human Agency, Material Agency, and Interpretative Schema, it is possible to dissect strands of interactions between agencies and structure that occur within a given time interval.

In the second theme that emerged from the Eaton *et al.* case study, Apple enacted a rule to control content within its app store by stating that *"apps containing content that may be found objectionable, for example, materials that may be considered pornographic, privacy-breaching,* *or bandwidth-hogging, or anything illegal, will be restricted"* (Cohen, 2008). However, shortly after the launch of the app store, third-party developers complained that their apps were being rejected or removed from the store, citing the content control rule, where the reasons were not clear to the developers (Eaton *et al.*, 2015: 228). Table 4.3 links the actions of Apple and the developers to the respective arrows in the SBF:

Table 4.3 – Negotiation of Content Control

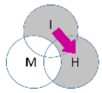
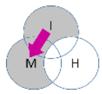
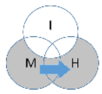
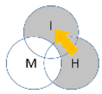
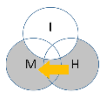
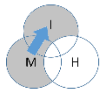
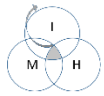
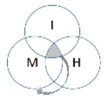
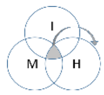
Action	**Interpretation**	**Arrow**
Apple publishes an app approval process stating that apps with objectionable content will be controlled or removed	Apple imposes a formal rule (Interpretive Schema) on application creators of restricting their ability to publish all apps (Human Agency)	 (#2)
Apple designs a set of criteria to identify pornographic, privacy-breaching, bandwidth-hogging, or otherwise illegal content on its apps store	Apple changes the design (Interpretive Schema) of the apps store to flag suspected apps with questionable content or unusual behaviours (Material Agency)	 (#5)
The app store rejects and eliminates apps that fall within the designed criteria, but also flags 'false positives' without objectionable content	The changed affordance (Material Agency) of the app store rejecting 'false positives' influences the application creators' disposition (Human Agency)	 (#4)
Third-party developers complain about the lack of transparency in the app approval process and the lack of clear rules – they ask for exceptions to be made	Application creators voice their objections (Human Agency) to Apple and advocate for exceptions to the formal rule (Interpretive Schema)	 (#1)
Apple introduces individual exceptions to objectionable content (i. e. calling out human reproductive organs is not offensive when used in a healthcare context)	Apple content controllers decide on granting exceptions (Human Agency) and incorporate them in the system (Material Agency)	 (#3)

Table 4.3 – Negotiation of Content Control

Action	Interpretation	Arrow
Apple looks at examples of rejected (and published) content and finds cases where disallowed apps are incongruent with the spirit of the ruleset	The discovery of incorrectly flagged content in the system (Material Agency) prompts the alteration of the rule set (Interpretive Schema) to allow for these legitimate uses	 (#6)
Apple modifies the rule set (boundary resource) and provides more transparency of what constitutes objectionable content	The interplay of all three circles (Human Agency, Material Agency, Interpretive Schema) prompts a change to the rule set (Interpretive Schema)	 (#9)
Apple incorporates the new ruleset into the algorithms that are tasked to detect objections	The same interplay triggers the incorporation of the new ruleset in the system (Material Agency)	 (#8)
Third-party developers are now able to publish (and sell) apps that were previously rejected by the app store	The same interplay equips application creators with the ability (Human Agency) to now publish apps that were previously rejected	 (#7)

This theme in the case brings forward the unanticipated conflicts between the intended design and the actual use cases across a multitude of heterogeneous developers in open-source communities. It again touches on all activated interactions (arrows) between the Venn diagram circles and spawns rule changes, algorithm modifications, and the formation of new (technical) abilities and routines from the constitutive middle space; thereby breaking down the paradox of simultaneous control and generativity. What follows is a third thought experiment of applying the SBF in the setting of a manual car park.

4.3 Manual car park thought experiment

"Theory without experiment is empty. Experiment without theory is blind."
(Archer et al., 2013: 182)

Let us assume a simple manual car park – the sociotechnical system consists of a perimeter fence, a barrier at the entry/exit points for purposes of access control and security, and a guard who is present 7x24 hours at this gate. The user pays a fixed fee upon ingress, is being handed a ticket showing the entry day and time and is then entitled to park for a maximum of eight hours. When the user leaves, the guard validates the ticket, ensures that the time span of eight hours has not been exceeded, and if it has, the guard charges a late fee. This basic process flow diagram captures the exchange between the user and the system, i.e., the facility and the attendant. Figure 4.1 lists the individual process steps for activities surrounding 'enter and park' and Figure 4.2 depicts the necessary steps to 'leave':

Figure 4.1 – Process Flow for Manual Car Park – Enter and Park

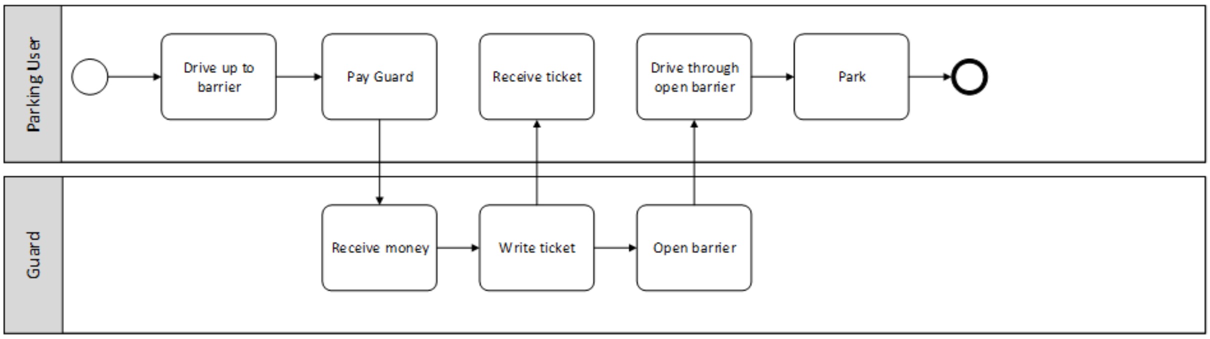
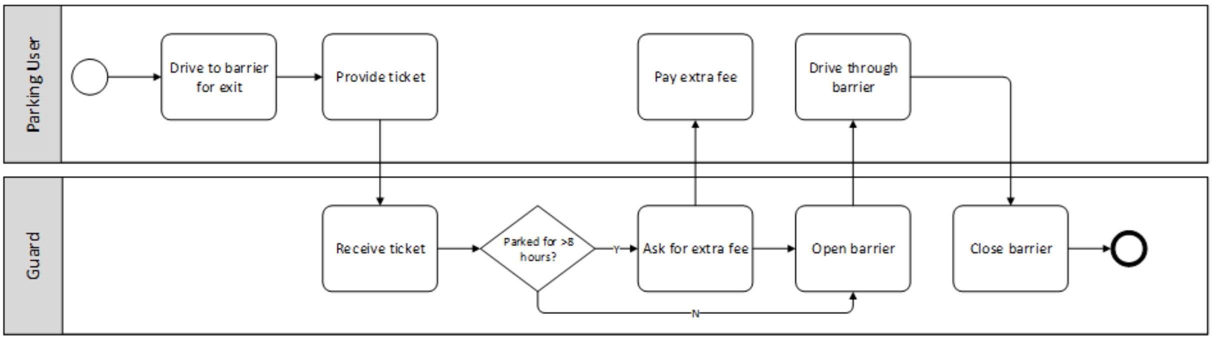


Figure 4.2 – Process Flow for Manual Car Park – Leave



The first assumed exchange between the parking user and the guard, recapped in Table 4.4, occurs under the premise that all steps in the process flows take place as intended:

Table 4.4 – System functions and interchange takes place as intended

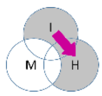
Action	Interpretation	Arrow
The driver approaches the barrier	The rule to stop in front of a barrier (Interpretive Schema) causes the driver to brake (Human Agency)	 (#2)

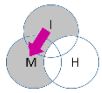
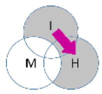
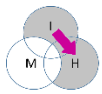
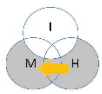
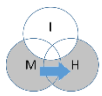
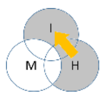
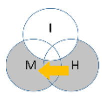
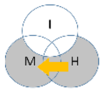
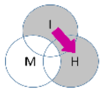
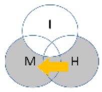
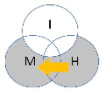
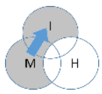
Table 4.4 – System functions and interchange takes place as intended		
Action	**Interpretation**	**Arrow**
The driver stops	The design of the barrier (Interpretive Schema) physically prevents the driver from proceeding (Material Agency)	 (#5)
The driver pays the guard	The rule to pay for parking (Interpretive Schema) prompts the driver to issue payment (Human Agency)	 (#2)
The driver receives the ticket	The rule to provide a receipt for payment (Interpretive Schema) triggers the guard to write the ticket (Human Agency)	 (#2)
The guard opens the barrier	The guard exercises his ability (Human Agency) to lift the gate (Material Agency)	 (#3)
The barrier and perimeter fence provide security to the car park	The affordance of the fence and barrier (Material Agency) keep trespassers away from the premises (Human Agency)	 (#4)
Usage of the car park has a general influence on other users	When people park their cars in rows (Human Agency) it reinforces the norm that all customers should park in rows (Interpretive Schema) as the action influences the norm	 (#1)
The driver enters the premises and parks the car	The driver proceeds through the open gate (Human Agency) and parks the car (Material Agency)	 (#3)

Table 4.4 – System functions and interchange takes place as intended

Action	**Interpretation**	**Arrow**
The driver returns to the car and drives to the exit	The driver approaches the guard again (Human Agency) and is stopped by the barrier (Material Agency)	 (#3)
The driver produces the ticket	The rule to show the ticket upon leaving the car park (Interpretive Schema) prompts for the driver to give the ticket to the guard (Human Agency)	 (#2)
The guard opens the barrier	The guard exercises his ability (Human Agency) to lift the gate (Material Agency)	 (#3)
The driver leaves the premises and the barrier closes	The driver proceeds through the open gate (Human Agency) and drives away, the barrier (Material Agency) is lowered by the guard (Human Agency)	 (#3)
Repeated usage "as intended" reinforces the status quo	The repeated non-problematic functioning of the system (Material Agency) reinforces the existing rule sets and standards (Interpretive Schema) across the car park – it is operating effectively and generating profit	 (#6)

Arrows 7 through 9 are omitted in this exchange since the system is in equilibrium where everything functions as designed. There is no apparent reason for the formation of new abilities, skills, disposition, routines, new technology, or new norms, rules, laws, or standards.

Let us adopt a scenario with an unintended consequence: the user accidentally drives through the barrier and damages it – assumedly because he or she is in a high vehicle, such as a

Sport's Utility Vehicle or pick-up truck and did not stop far enough away from the barrier arm where it would still be in the person's field of vision. In this case, we have a diminished Human Agency (effectivity) in that the driver is not able to see the barrier, which turns into a negative affordance by resisting entry. The unintended interaction between the user and the system is reflected in Table 4.5:

Table 4.5 – User accidentally damages barrier

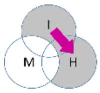
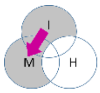
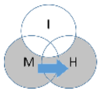
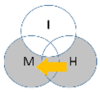
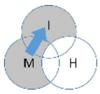
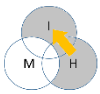
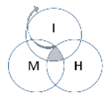
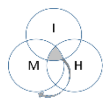
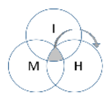
Action	**Interpretation**	**Arrow**
The barrier prohibits unauthorized entry	The rule (Interpretive Schema) is designed for the driver to stop (Human Agency)	 (#2)
	The technical design of the barrier (Interpretive Schema) is prohibiting the system (Material Agency) from letting the driver enter	 (#5)
	The barrier (Material Agency) physically prevents the driver to pass through (Human Agency)	 (#4)
	Driving forward (Human Agency) clashes with Material Agency that should prevent entry	 (#3)
The actions have a larger effect on the system	The broken barrier (Material Agency) drives the rule without human intervention that one cannot pass through a physical barrier (Interpretive Schema)	 (#6)
	The person's inability (Human Agency) to manoeuvre the technical setup (by breaking through the barrier) demonstrates a gap in the	 (#1)

Table 4.5 – User accidentally damages barrier

Action	**Interpretation**	**Arrow**
	technical standard (Interpretive Schema)	
The actions change the system	The technical design (Interpretive Schema) may be changed to raise the barrier height and equip the arm with warning lights for improved visibility	 (#9)
	The design changes are physically incorporated into the system by installing a higher barrier arm with red-flashing warning lights (Material Agency)	 (#8)
	Drivers are better able to see the obstruction (Human Agency) and avoid driving through a closed barrier	 (#7)

In this example, it is apparent that the changed design (arrow 9), modified system (arrow 8), and enhanced human effectivity (arrow 7) constitutively emerged from the entangled three-circle intersection. However, Analytical Dualism is expected to allow us to pinpoint the impact of Material Agency on Interpretive Schema (arrow 6) as the central contributing element that prompted the formational activities brought about through the last three arrows. The thought experiment highlights the importance of time in this process – arrows 7 through 9 spin off as an <u>answer</u> to a situation that took place within the brackets of a specific time interval. This is consistent with Archer (2010: 238) where structure (Interpretive Schema) predates action (Arrow 6), is followed by structural elaboration (arrow 9), and a subsequent reification of altered capabilities in systems (arrow 8) and/or humans (arrow 7).

According to Archer, what then follows is a new cycle of instantiation where the changed baseline has the potential to result in the next effect. We can take the thought experiment further by assuming a new unintended consequence stemming from the installed feature of red-flashing warning lights. Let us assume that potential car park customers misinterpret flashing lights as a warning not to approach the area. This would be a misinterpretation tied to the top circle of the Venn diagram (Interpretive Schema) since it is perfectly safe to drive up to the gate, albeit slowly so as not to damage it. In analysing each individual interaction via the framework, we determine the following in Table 4.6:

Table 4.6 – User misinterprets flashing lights as a signal to stay away

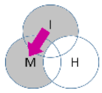
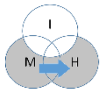
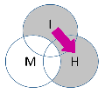
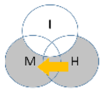
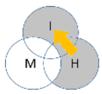
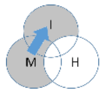
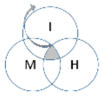
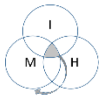
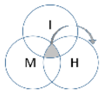
Action	**Interpretation**	**Arrow**
The warning lights flash	The barrier is a technical design element (Interpretive Schema) to make the driver stop and the warning lights are intended to draw attention to the obstruction (Material Agency)	 (#5)
	The barrier physically blocks the pathway and the warning lights are flashing (Material Agency) – the lights are noticed by the user (Human Agency)	 (#4)
	The user (mis-)interprets (Human Agency) the warning lights as a signal to stay away rather than as an invitation to proceed with caution (Interpretive Schema)	 (#2)
The potential customer (user) drives away	The driver does not engage with the system (Material Agency), i.e., he or she does not approach (Human Agency)	 (#3)
	The human's disposition not to use the car park (Human Agency), considering its *perceived* danger, results in profit loss for the car park operator (Interpretive Schema)	 (#1)

Table 4.6 – User misinterprets flashing lights as a signal to stay away

Action	**Interpretation**	**Arrow**
	The technical possibilities within the system (Material Agency) would allow for a more nuanced warning mechanism regarding the setup of the gate	 (#6)
The actions change the system	The technical design (Interpretive Schema) may be altered to activate the warning lights once a car gets into proximity of the gate	 (#9)
	The design changes are physically incorporated into the system through sensors that activate flashing lights (Material Agency) when a car is in front of the gate	 (#8)
	Drivers are no longer deterred from approaching the car park yet alerted as to the barrier's presence when needed (Human Agency)	 (#7)

This iteration of the hypothetical example crystallizes, via the application of Analytical Dualism, the driver's misinterpretation of the warning lights (arrow 2) and the consequences caused by refraining from parking (arrow 1). It underlines the flawed exchange between Human Agency and Interpretive Schema as the featured dissonance in the framework. Subsequently, arrows 7 through 9 provide a modified response to this situation and the cycle starts anew.

The possibility to analytically point to one or more contributing arrows in the framework when probing for unintended consequences is a prerequisite to the design of an effective case study. Next follows a detailed description of the case.

5 Case Description

"1755 – born is a city facing the sea" (Santander-Convention-Bureau)

5.1 Overview of the City of Santander

"There is a lightness associated with the play of ideas, improvisation, and experimentation." (Weick, 1996: 312)

Source: Andrey Khrobostov / Alamy Stock Photo

Santander is the capital of the autonomous community and historical region of Cantabria, Spain with a total population of 173,539 residents as of January 1, 2019 (Estadística, 2019). It covers an area of approximately 33 km^2 and is located at the northern coast of Spain, facing the Bay of Biscay in an extension of the Atlantic Ocean. It has been built on hills and steep slopes that have naturally divided the city into distinct areas (Santander-Tourism-Bureau, 2020). The Port of Santander has occupied an important role since the middle ages and supported the steady growth of the city. The Bank of Santander ("Banco Santander") was founded in the city in 1857 – initially to facilitate trade between the Port of Santander and Latin America (Banco-Santander, 2020). Most of the city's economic activity is now anchored in the service sector with tourism in the summer months playing a major role (Ringrose, 2005).

In line with Archer's assumption that legacy structure precedes agency, Santander's geography, and age introduce significant limitations for parking in the city. This path dependence is especially constraining in the downtown district where a subset of streets has been equipped with IoT parking sensors. This area consists almost exclusively of narrow one-way streets that are flanked by mixed-use buildings with shops and restaurants on the ground floor and residences on the upper floors. The tangle of streets and intersections is situated between the ferry port and boat harbour on its sides and it is further confined by the Bay of Biscay in front and a steep hill that rises immediately behind the downtown area.

Source: Public Website

Due to its climate and location on the Iberian Peninsula, Santander experiences a surge of visitors during the summer months predominantly from other parts of Spain, other European nations, and the United Kingdom. The city is especially attractive to French and British tourists since it lies only 215 kilometres from the French border and is connected via regular ferry routes to Plymouth and Portsmouth in the UK. Its climate is classified as temperate, without a dry season, with warm summers as type “Cfb” on the Köppen-Geiger climate type map of Europe, and with an average of 1,649 total sunshine hours per year (Peel *et al.*, 2007). These temperate conditions also make it a preferred summer vacation destination for people from all over Spain. It is estimated that Santander’s population quadruples between the months of June to September each year, which puts immense pressures on the already crowded downtown area and exacerbates the scarcity of parking spaces. The city’s average relative humidity is 74% and, unlike most other parts of Spain, the region receives a fair amount of rainfall with 1,129 mm as the annual average on 124 precipitation days (Meteorología, 2020).

5.2 Introduction to Santander’s Smart City goals

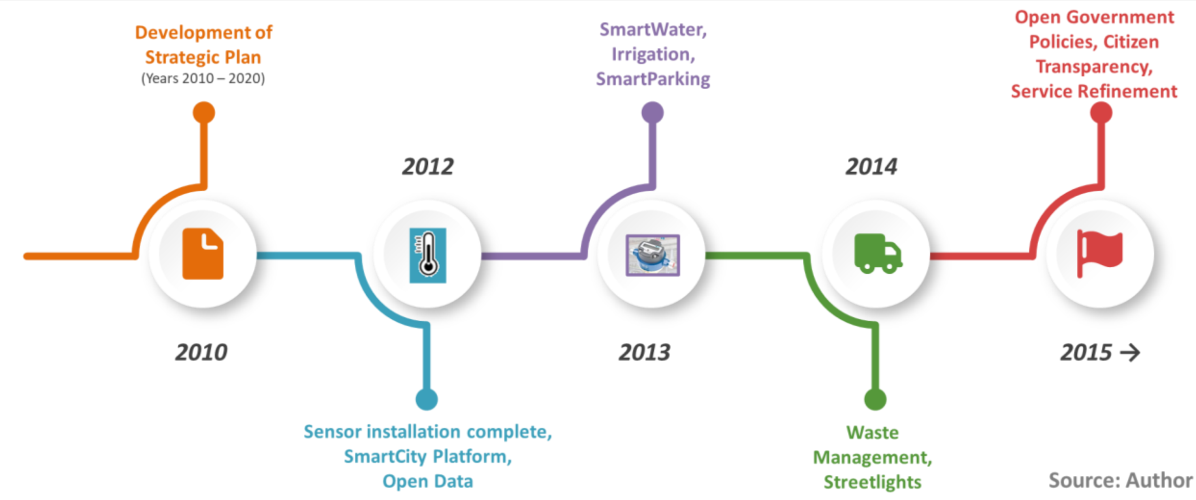
“Smart City is the process of improving the way of managing a city.”

(Informant C1)

SANTANDER Smart City

For the past decade, the city of Santander has tightly collaborated with the University of Cantabria’s Department of Communication’s Engineering to create the technological capabilities for Smart Santander. The city started its Smart City initiative in early 2010 with the vision to use technology that is focused on citizen’s needs. At that time, the concept of a Smart City was still in its infancy and the city embarked on creating Smart Santander – an experimental testing facility for research on architectures, key enabling technologies, services, and applications for the Internet of Things (IoT) in the setting of a Smart City. In concert, the city started the effort to diagnose and evaluate municipal service areas, build a transformation model, roadmap, and define key performance indicators (Ayuntamiento-de-Santander, 2019). Figure 5.1 arranges the timeline of individual Smart Santander capabilities as derived from the interviews:

Figure 5.1 – Smart Santander Phases and Timeline



The underlying objective of Smart Santander is to improve the quality of life of its residents and to foster a more sustainable city – through steps of enhancing city services in a coordinated fashion. This was expanded-upon by a city representative who stressed that technology is simply an enabler and emphasized the need to coordinate between different city services and to exchange information: *"Traditionally, we looked at improvements to different services in the city separately – much like it happens in other cities around the world. You look at parking services, you work with traffic, and you work with your data, but you just communicate with your colleagues when you have a problem. So, there wasn't coordinated action between the different areas. The idea of this Smart City initiative is to increase our efficiency and so we must provide better services to our citizens and increase the quality of life. The way we can do this is if we have more information and more control over our services."* (Informant C1).

This is echoed by representatives of the University of Cantabria who agreed with the notion that not everything depends on technology. The outcome is often contingent on the behaviour of citizens or service provider employees: *"It depends on many factors, but in a Smart City you have to take everything into account. The technology is the tool that will help you do things in a better way, but it's not the solution for everything. That's our lesson that we learned."* (Informant U1).

The circumstance that Santander is a city with less than 175,000 inhabitants has been helpful, especially in the early stages of Smart Santander, since small municipalities have more leeway to work around procedures or implement non-standard processes. In addition, approval activities are simpler and communication pathways are shorter than in larger administrations.

It is also crucial to understand the current state of service delivery and to involve residents right from the start in defining how services should be enhanced – or as the city sees it: *"When* *you work with citizens, you have to convince them that this will help them"* (Informant C1). This is underscored by a representative of the University of Cantabria who commented that *"they [the citizens] must not perceive technology as a hindrance for them, but as an instrument to improve the quality of live for themselves and the society in general."* (Informant U2).

The inclusion of technology in reaching the Smart Santander goals is a key component to building the future roadmap. The importance of having a comprehensive plan must not be underestimated, especially since cities typically run a set of existing (legacy) systems that need to be carefully integrated with new Smart City capabilities.

The European Commission (EC) hosted a Smart City summit in Santander in 2009 where several cities presented their projects and findings. At that time, all Smart City research in Europe was carried-out in labs without the ability to replicate real life conditions outdoors where citizens use the functionality and where sensors and other devices are subjected to changing weather conditions such as rain, heat, etc. The EC Smart City summit offered an opportunity for Europe to assume a global leadership role in experimenting with IoT technologies in an urban landscape. The EC decided to grant funding to Santander because of its unique geographic and demographic attributes: it is a port city at the ocean, close to mountains, and its size suggested a straight-forward deployment of IoT technologies. This makes Santander an exemplary case study with the potential to produce more unintended consequences.

The largest investment was the installation of sensors that are comprised of fixed and mobile sensor nodes, Near Field Communication (NFC) tags, and gateway devices to collect the information. The cost of approximately one million Euro was evenly split between the EC and the Government of Cantabria.

During the early stages of the initiative, the project team learned a lot about sensor technology. The first parking sensors to be tested contained two 'always on' radios, which resulted in excessive battery drainage that prompted replacements after only a few months of usage. This is unsustainable in an environment where parking sensors are buried under asphalt and accessing them is difficult and costly. The next generation of parking sensors was much more energy efficient, but the casing was not watertight, which ultimately caused an electrical failure in all buried parking sensors. These experiences confirm the pivotal role of pilots that test the technology in small scenarios before deploying devices on a larger scale: the first 'test bed' for Smart Santander's parking sensors was a portion of the university campus parking lot.

Technologists from the University of Cantabria underscore funding limitations that presented themselves in a city of only 174,000 residents: *"If you want to deploy one million sensors, you can invest in building an expensive custom-built box to house them. But if you ultimately only deploy a few hundred sensors, you don't have the economies of scale, so you don't have the* *return there. You use what you have in the market and you try to adapt it to the conditions of Santander."* (Informant U3).

The city began installing IoT sensors in September of 2010 and started receiving data from these devices in 2011. By 2012, the city had deployed more than 12,000 sensors within its borders and started the integration of sensor data (temperature, noise, light, CO_2 emissions, and the presence of objects) into the provision of urban services. While most of the service information was still only accessible in separate databases, as vertical information silos, the city nevertheless experienced first improvements in operational efficiencies (Ayuntamiento-de-Santander, 2019). Santander's aim was to enable companies, designers, and technicians to experiment with IoT technologies and to evaluate if (and how) their solutions work in an environment that resembles actual operational conditions. Because testing takes place in a real city, companies can gather valuable feedback on the technical efficacy of their solutions end-to-end: from collecting massive amounts of data across these 12,000 sensors, to transmission of data, all the way to ingestion of these data into an application. In addition to testing the technology, companies are able to gauge user acceptance, service usability, and performance with real users who are the citizens of Santander (Lanza *et al.*, 2016).

Figure 5.2 – Santander IoT Sensor Placement
(Reproduced with permission)

Figure 5.2 depicts the distribution of the city's sensor network that is comprised of approximately 2,000 static environmental sensors on lampposts and building facades to measure temperature, noise, light, CO_2 emissions, and the presence of cars. This is complemented by roughly 150 mobile CO_2 sensors in public vehicles such as buses, taxis, and police cars. There are approximately 60 devices that have been deployed at main thoroughfares through which drivers enter the city and that provide data on traffic volumes, road occupancy, vehicle speed, and traffic queue length. Availability of parking spaces in main parking zones of the city centre is detected by approximately 375 ferromagnetic sensors that are buried under the asphalt. Three city parks have been equipped with approximately 50 sensors to control irrigation by measuring soil moisture, temperature, humidity, rain precipitation, and wind conditions. More than 2,000 NFC/QR Code tags have been distributed across key locations in the city at transportation hubs (bus stops, taxi queues), sight-seeing points of interest (monuments, buildings), and shops. Once one of these tags is read by the user, the Smart City platform database captures the event and records publicly available data from the user's mobile device – for example, country of origin based on the cellular network roaming profile. The city's waste management system has been equipped with approximately 6,000 devices (sensors and RFID/NFC tags) to obtain real time information on bin location, status, and fill level of waste receptacles and containers. The remainder of the city's sensor network is distributed over many participating residents of Santander who signed up voluntarily to let their mobile phones double as sensing devices. The technology utilizes the built-in functionality of a device to measure temperature and noise levels. These data pieces are then complemented with the device carrier's GPS location information and transmitted to the Smart Santander platform. In addition, users can report incidents or events in the city that are in turn distributed to subscribers of such information (Lanza *et al.*, 2016).

The introduction of the city's data platform, Smart Santander, facilitated horizontal integration between previously disjointed city services, including dashboards for improved service management (Ayuntamiento-de-Santander, 2019). Santander espouses an open data policy in that all base data from sensors are freely available to whoever wants to access these data. This stimulates an open innovation ecosystem in which companies develop their own applications and services. The data can be gathered through a standard process utilizing ReST-API, a Representational State Transfer-Application Program Interface, built as a web service, that allows the integration of sensor data into an application. This is a valuable technical feature in that the IoT devices have been equipped with two radio transmitters that can be activated on-demand. One handles the transmission of the actual sensor data (such as temperature, lighting conditions, etc.) and a second transmitter allows for the device to be reprogrammed over the air. This feature allows testing of different transmission protocols across the network to determine which protocol is most appropriate for a given use case.

The city was able to build stakeholder support for the program early; here, dashboards with pertinent information play a key role. These help service providers and city administration personnel manage services better. It has been a priority for the technical arm of Smart Santander to work with officials in the municipality to design the dashboards that are most useful to them.

From 2015 onwards, Santander has entered a growth phase that builds upon the previous three stages of initiation, vertical, and then horizontal integration. Within this context, the city representative emphasizes the most important building block of a Smart City initiative: open government policies and complete transparency with citizens. Prior to Smart Santander, there was a culture where companies and citizens were reluctant to get involved. *"You had to push or incentivize them to work with you"* as per Informant C3, a city official. Now, interested citizens come to the university or the municipality to propose their own ideas. Smart Santander operates a web portal called “Santander City Brain” that acts as an idea collection platform. Sponsored by Banco Santander, the city administration and/or service providers pose ‘challenges’ to citizens to respond with ideas through the vehicle of a contest. This delivers important insights into what the city should be focusing on next. Another citizen engagement program is a website that solicits input to a participatory budgeting process where citizens vote on spending proposals for the city’s annual Smart City innovation budget of 1.5 million Euro (in 2019).

The EC’s stimulus program, “Horizon 2020”, is tasked with improving Europe’s economy, science/technology base, and industrial competitiveness through a wide-spread public funding initiative (Kalisz and Aluchna, 2012). With more than 300 partners focusing on Smart City technologies, at a grant level of 154 million Euro, the University of Cantabria is an active participant on several new projects. Smart Santander’s original goal of being an urban laboratory for companies to collaborate has been vastly exceeded. By October 2019, Santander is the testing ground for more than 27 European projects that rely on the city’s IoT capabilities and the resident’s willingness to pilot these new technologies, processes, and concepts. The city was a founding member of Spain’s Smart City network – a group that shares best practices across its 80 member cities.

5.3 Surrounding ecosystem of Smart Santander service delivery

“In the beginning, we were naïve and thought that everything was going to work properly.” (Informant C1)

All components of Santander’s Smart City service delivery framework rely on the integrated sensor data described in Section 5.2. All purchases, such as IoT devices or service contracts, follow a strict public tender process to account for maximum transparency in spending public funds. The city bundled the procurement of a city service, such as water and waste management, parking, street lighting, etc. with the requirement to interface with the Smart Santander platform. This leads to end-to-end ownership of the service by the provider including technology aspects of the offering; thereby, eliminating the possibility of blaming a third party if there are technological problems. Based on a city representative’s feedback, service providers had mixed reactions to this requirement – ranging from acceptance, in cases where service providers possess technical proficiency themselves, to choosing not to participate in the tender if the service provider found technology co-delivery untenable.

Santander awards contracts to successful bidders for multi-year engagements. For services that are directly paid for by citizens, such as water/waste management and parking, the provider collects payments from citizens for delivered services. The service delivery company then pays a fixed monthly amount to the city. This allows providers to influence their profit margin in three ways: 1) through increasing revenue (within agreed pricing structures), 2) by enticing more people to use the service, and 3) by decreasing operating cost for the company. For services that are directly paid for by the city, such as street lighting, the city does pay the supplier, but the company is expected to meet certain agreed-upon energy and/or efficiency savings. As an example, there is a system that allows modification to the luminosity level of every streetlight in the city. The municipality issued a tender with a 75% energy cost savings threshold and the winning bidder committed to 80% savings within 12 months. If the provider were to fall short, money is being contractually withheld by the city as a penalty; conversely, if the provider exceeds the target, the company will receive a bonus.

Some of the interviews revealed that three issues relating to technology are frequently encountered with service providers: 1) Since the service provider owns the solution end-to-end, the choice which technology to use remains with the provider. At times, this has led to compatibility issues with Smart Santander's requirements and the seamless integration between services. 2) Service providers with a lack of technical acumen have subcontracted some or all of the technology deliverables to third parties, a practice that has led to project delays, disjointed service delivery, and passing blame between entities when problems arose. 3) A Santander city representative states that *"the paper says 'yes' to everything, but after that you have to implement it."* (Informant C1). There is a tendency for providers to over-promise in their proposal(s) and then having to face reality of being unable to deliver to specifications. This is often due to optimistic assumptions that are made regarding the technology and how it will behave in real life conditions: *"What works in in a 'Lego model' does not necessarily work in a real city."* (Informant U1).

Santander Smart City operates the following services, within their IoT sensor ecosystem, that are delivered alongside the parking solution:

Water – all household water consumption data is transmitted from individual meters via the cellular network to the service provider. This has eliminated the need for sending out personnel to read water meters and every city resident can review their water consumption via a web portal that also shows the comparison between an individual unit's water use with the neighbourhood average. If an individual unit's consumption exceeds the average, the party is alerted via a text message, a practice that has greatly contributed to early detection and remediation of water leaks. The application also allows the reporting of incidents, such as an obvious water leak, and provides information on water quality measurements for different parts of the city. In addition, the municipality has placed two electronic panels in high-traffic pedestrian areas that display water quality measurements.

Irrigation – the city installed approximately 50 sensors in three city parks that measure ground moisture, temperature, humidity, rain accumulation, and wind speed as well as direction. The system then controls lawn and tree/plant irrigation in response to environmental needs that are relayed by the sensor data.

Waste – the city's waste management service provider has placed large containers for biodegradable, paper, plastic, and residual waste throughout the city. Biodegradable and residual waste containers are collected daily, but containers for paper and plastic are only emptied as needed. These containers are outfitted with IoT devices to track their location (via GPS coordinates), operating status, and fill levels. If the fill level exceeds 75% of the container's volume, the system sends a signal to arrange collection of the container's contents. The waste pickup vehicles are also equipped with location sensors that allow for the optimal route matching between containers needing to be attended to and available vehicles. Each container has self-diagnostics built-in that can detect some types of malfunctioning of the electrical system or the container's moving parts. When street cleaning personnel passes by a container, the person can scan the RFID tag and report a visible problem, via an app, that may otherwise not have been picked up by the container's self-diagnostic feature. The app is also accessible for citizens, on any mobile device, who want to report a trash-related problem to the service provider. The user's GPS coordinates identify the location of the receptacle and, if desired, the user can attach a picture for clarity or context. All data collected feed back to the Smart Santander platform from which different dashboards are accessible: one set that allows the service provider to gain insight into operational details, for example which containers are broken, which trash-pick up routes have been completed or are delayed, the status of the service, etc. The second set of dashboards aggregate information for the city, such as the summary of the overall percentage of malfunctioning containers.

Streetlights – Santander's 22,700 lighting poles have all been equipped with new LED technology that allows for rapid adjustment of a lamp's luminosity level. Lights are dimmed in areas where there is infrequent traffic at night. These areas are also furnished with motion sensors that will, on-demand, increase the light level when there is a passer-by or an approaching vehicle. The city expects to save 80% in energy cost and 35% in maintenance cost through this practice.

Tourism – the city collects data that is publicly available through the local Telefónica mobile network. Once the network provider detects that the Subscriber Identity Module (SIM) card in the mobile phone of a registered user is in 'roaming' mode, meaning that its country of origin is not Spain, the provider is able to determine the originating country and the approximate position of the device. This information is then aggregated and sent to the Smart Santander platform. The city thus knows how many foreign visitors are present at any given time and where they are from. The platform then combines data that have been collected by the city's tourist service, such as the occupancy level of hotels, tickets sold at cultural centres, or number of visitors in the tourist information office. It allows Santander to provide tailor-made service offerings as well as conduct marketing/advertising campaigns in other places (cities and countries).

5.4 Smart Santander parking solution

"The human part in the city is very important." (Informant C3)

Figure 5.3 – Santander OLA Terminal
(Personal photo)

Santander implemented street parking terminals (so called "OLA terminals"), that are shown in Figure 5.3, more than 20 years ago to increase city revenue. Paid parking is in effect on weekdays from 10am to 2pm and from 4pm to 8pm. The paid parking time on Saturdays is from 10am to 2pm. Parking during these times is limited to a maximum of two hours – it is unrestricted and free of charge during all other times, including Sundays, and public holidays. While paid parking is in effect, the user is not allowed to add any additional time in excess of two hours (120 minutes) for the same spot or a spot nearby, i.e., in the same street. The first iteration of Santander's parking terminals required cash (coin) payment at the terminal, where then a receipt was printed – the receipt had to be placed behind the windshield. Parking controllers patrolled streets on foot and issued violation tickets, on the spot, to drivers who failed to provide adequate proof of payment.

Dornier, LLC is a privately-owned company with approximately 50 employees and the sole administrator of parking services in Santander. One representative of the city administration highlighted that, prior to the implementation of IoT parking technologies, everything was kept in Microsoft Excel spreadsheets and every violation ticket had to be entered and tracked manually. Dornier was awarded the public tender to implement an ambitious street parking modernization program and to operate it on behalf of the city. The results have exceeded expectations and the cost for the city has decreased steadily. In 2018, Dornier was able to achieve an annual revenue of 2,880,000 € out of which it transferred 1,340,000 € to the city; the delta of 1,540,000 € (53% of the achieved annual revenue) remains with Dornier's as their profit.

The initiative centres around three major areas where detailed process maps, outlining the individual process steps, and data flow diagrams, are included in Sections 5.6 and 5.7 respectively:

5.4.1 Payment for parking spots

Dornier upgraded all existing **street parking terminals** ("OLA terminals"), and installed new ones throughout Santander, for a total of 304 units as of October 2019. The new terminals cater to the region's large contingent of foreign visitors by offering, besides Spanish, for transactions to be conducted in English, French, and German. The terminal requires entering a car's license plate number and allows for payment via pre-paid cards or coins (see Process 08 in Section 5.6). The user has the option of extending an active parking session, up to the maximum allowed parking time (two hours), by entering a code number that was printed on the original parking receipt. The code number links this transaction to an already existing active parking session (see detailed Process 09 in Section 5.6). All active parking sessions are stored in a database that is used to detect potential subsequent parking violations (there is no need to display the parking receipt behind the car's windshield). Prior to the installation of the latest generation of street parking terminals, coins were collected daily from all terminals, causing inefficiencies as an unintended consequence where locations were emptied that had hardly accumulated any cash. The new terminals keep track of how many coins have been deposited and send out a signal to schedule collection once a certain threshold has been reached.

Figure 5.4 – Telpark Application
(Reproduced with permission)

The second major addition to payment for parking has been the introduction of the **Telpark** mobile application shown in Figure 5.4. It can be downloaded from Google Play (for Android phones) or the App Store (for Apple devices). The user is enabled to create an account with his/her reference data: country, e-mail, name, password, payment method(s), and license plates for vehicles that the user wishes to register (see Process 01 in Section 5.6). In lieu of using a street parking terminal, the driver can initiate and pay for parking sessions via the Telpark application (see Process 05 in Section 5.6), extend parking sessions in five-minute increments (see Process 06 in Section 5.6), and terminate parking sessions (see Process 07 in Section 5.6). Like parking sessions that are initiated through street parking terminals, Telpark updates the central database that tracks all active parking sessions, and that forms the base for detecting parking violations. Telpark enables cash-less payments, and unlike street parking terminals that operate based on pre-paid parking times, it only charges the user for the actual time that was parked.

5.4.2 Parking violations

Dornier estimates a ratio of cars to residents of 0.6 or, inverted, a ratio of 1.67 residents to one car with a total volume of approximately 1,800 parking spaces throughout the city that must be patrolled. The personnel cost would be much higher if enforcement were to take place by parking controllers investigating streets on foot.

Figure 5.5 – Scanning Vehicle
(Personal photo)

After the system upgrade, Dornier scans cars with **camera-equipped electric vehicles** (Figure 5.5) that drive down a street and process 2,000 to 2,500 license plates per hour (see Process 11 in Section 5.6). The company largely discontinued the practice of manual enforcement and restricts it to certain downtown streets with significant vehicle turnover, where enforcers on foot are still the easiest and most practical solution (despite the human limitation of not being able to process more than 250 to 300 license plates per hour). All scanned license plates, whether through camera-equipped vehicles or manual checking, are compared against the database that tracks all active parking sessions. For all unauthorized license plates, the system creates a record in a parking violation database (see Process 12 in Section 5.6).

Once the infraction has been recorded, it must be **validated by a parking controller**. He or she is dispatched based on the record that was opened in the parking violations database. Most parking controllers are on motor bikes and are thus able to quickly reach an allegedly offending vehicle to document the violation. The state of Cantabria enforces the rule that more than one picture must be taken as proof of the offense. In the past, the practice was to only take one picture of the vehicle in question, which as an unintended consequence, exposed the company to a multitude of complaints, and resulted in a peak rate of 55% of parking citations being contested in court. The practice now is for the parking controller to take three pictures (back of vehicle with license plate, front of vehicle, side of vehicle facing the curb). This validates the vehicle’s identification via the license plate, confirms its position, and documents that it is stationary (see Process 13 in Section 5.6). The number of contested tickets has decreased by 60% and is now exceedingly low according to officials at Dornier.

The company issues approximately 240 parking violation tickets per (work-)day or approximately 5,000 violations per month on behalf of the city (see Process 14 in Section 5.6). There are relatively few challenged tickets and most successful contestations are due to user error. One common instance is for a user to have two license plates registered in the Telpark profile, but having selected the wrong license plate for a particular parking session. These cases are very often forgiven since the person did in fact pay, albeit for the wrong car. The recipient of a parking violation ticket has the choice of paying via the Telpark application, by mail, or in person.

5.4.3 Parking sensors

By 2012, the city in partnership with the University of Cantabria, started deploying ferromagnetic parking sensors that are buried under the asphalt. These sensors are distributed across an area of approximately 10x10 blocks within the city's downtown core. Figure 5.6 contains a picture of the sensor (on the left) and a sensor's placement in the street (on the right). While sensors are generally invisible, and meant to be as such, the example shows an exposed sensor head marked by the red circle.

Figure 5.6 – Parking Sensor
(Personal photo)

The implementation team experienced a fundamental problem with the first sensor generation in that the dual-radio transmission method resulted in excessive battery depletion and the sensors had to be replaced within a few months. After resolving this unintended consequence, the second generation of sensors worked well with regards to battery power consumption, but the casing was not waterproof – it allowed moisture ingress that ultimately caused all sensors to short-circuit. Replacing sensors is costly since it requires blocking the road and breaking through the pavement. The third generation of sensors addressed both problems and the city/university proceeded with deploying approximately 375 devices. These devices detect metal density changes in a cone-shaped area above the sensor and thus determines if the space above it is free or occupied.

Figure 5.7 – Smart Santander Parking Space Availability
(Reproduced with permission)

The parking space availability data is accessible via the Smart Santander application (see Process 02 in Section 5.6). Figure 5.7 portrays the status of each sensor: blue = parking space is available and dark grey = parking space is occupied. The yellow symbols are temperature sensors and do not relate to parking space availability. The second method to get an overview of available parking spaces and their approximate location is via street display panels (see Process 03 in Section 5.6). The city placed several panels at entrance ways into the downtown area that show summary information of available spaces per parking zone (see upper part of Figure 5.8) and detailed street-level information for a given parking zone (see lower part of Figure 5.8). Aside from drivers who use parking availability information to find spaces, these data are being used by police, city officials, and other decision makers who benefit from having visibility of the overall parking volume of Santander.

Figure 5.8 – Street Display Panel
(Personal photo)

5.5 Santander parking stakeholders

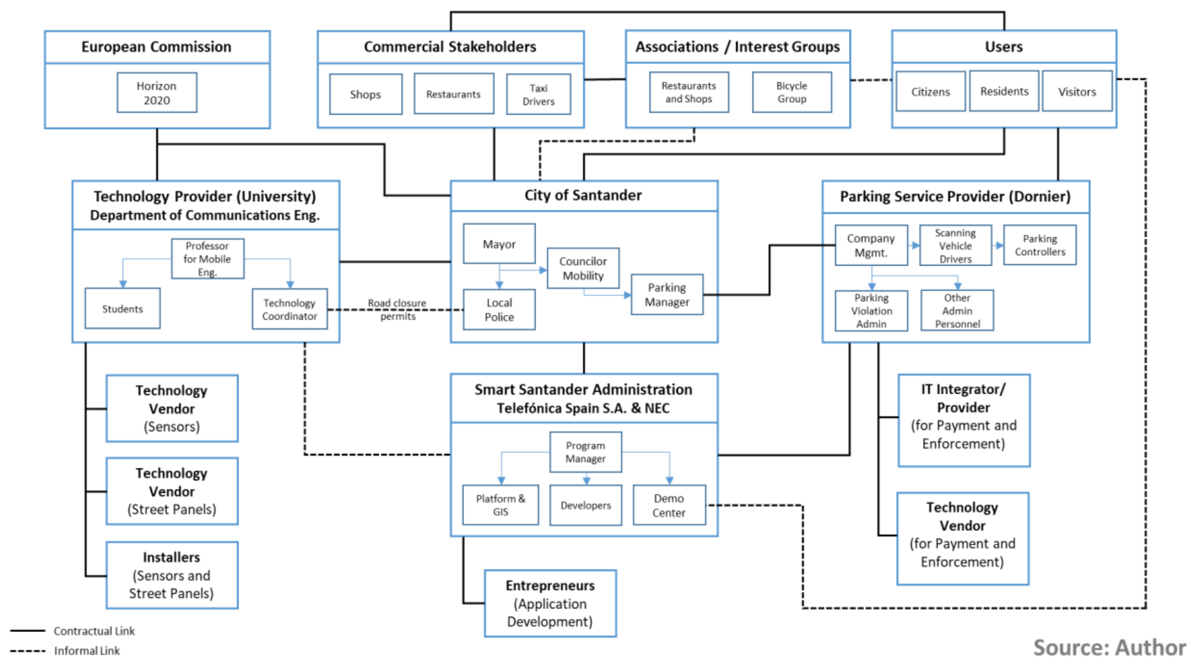
“Often, I park my car here.” (Informant R6)

The research centres on capturing diverse perspectives to increase the insightfulness of data interpretation and model development. Morell (2018: 250) distinguishes between six useful perspectives to examine unintended consequences:

1. Close observers (of program operations and outcomes)
2. Affected individuals (either directly or indirectly)
3. Evaluators (with experience but not directly connected to the program)
4. Distant informed observers (with opinions worth considering)
5. Sceptics and opponents (with counterweight opinions)
6. Intellectual or societal foundations (expressing an opinion of the impact)

Figure 5.9 contains a stakeholder relational map outlining the communication paths and contractual (solid lines) as well as informal (dotted lines) links between major stakeholders within Santander's parking ecosystem. It follows Missonier and Loufrani-Fedida's (2014) visualization technique of a front-end stakeholder network:

Figure 5.9 – Santander Parking Stakeholders



Source: Author

The **Technology Provider (University)** is the Department of Communications Engineering at the University of Cantabria and the overall designer and integrator of the parking solution. In addition to architecting the technical framework, the university chose the **Technology Vendors** for sensors and street panels and handled all procurement-related activities. The department ran several small pilots in the university's parking lot to select the appropriate sensor type. The university then sub-contracted two local companies (**Installers**) to physically place sensors in the street, while coordinating necessary road closures with the **Local Police**, and to install display panels at prominent locations in the city. While the vendors supplied the technology, the university conceived the solution and supervised the effort end-to-end.

Smart Santander Administration: Telefónica Spain S.A. and NEC Corporation, the Japanese multinational Information Technology and electronics company, created a partnership that provides Smart City administration services to several Spanish cities with Santander being one of them. Telefónica and NEC act as coordinators for sharing knowledge and best practices across a network of cities in Spain. The former, as one of the largest telecommunications companies in the world, and with its market penetration in Spain, is handling all telecommunications aspects within the Smart City framework on behalf of the City of Santander. Telefónica owns the advancement of strategy, development of the multi-year roadmap, administration of the Smart City concept, and management of the initiative overall. The company creates and operates, in concert with NEC Corporation, the Smart Santander platform and Global Information System for collecting and disseminating data across the entire city.

Figure 5.10 – Smart Santander Demonstration Center (Outside and Inside)
(Reproduced with permission)

Santander has established a Smart City demonstration centre in the Palacio de Riva-Herrera, a 16th century national monument (Figure 5.10). Its hands-on technology exhibit allows visitors to understand and engage with the new technology. The teams of Telefónica and NEC are continually expanding and refining the data that is stored in the Smart Santander platform for different city services so that they can be combined in intra-city services dashboards.

Entrepreneurs: Santander subscribes to an open data concept where almost all raw data that is collected by sensors is made available to individuals, universities, and companies for subsequent use. These entities can develop their own application based on the data that have been made available for parking.

Users: From a meta-data perspective, the city as well as the Smart Santander Administration are separating end-users into three categories: Visitors, citizens, and residents. Visitors are individuals who do not live permanently in Santander, such as tourists, business travellers, or out-of-town students. Citizens are registered with the municipality, have Santander listed as their domicile on Spain’s national ID card, and live anywhere within the city limits. Residents are a subset of the citizen population and, in the case of street parking, have a special permit to park within a zone. This annual permit can be obtained from the Parking Service Provider (Dornier) for a flat fee and enables the license plate holder to park in their assigned residential zone at a reduced cost. The resident’s car is not subjected to the two-hour maximum parking time. Once residents leave their pre-paid zone, they are regarded like any other citizen who needs to pay for parking. The Smart Santander Administration routinely reaches out to citizens and residents to be participants in pilot implementations by directly engaging with the university and/or the city.

Parking Service Provider (Dornier): This is a privately-owned company that operates parking services for Santander under a five-year contract that was awarded to them in 2016. Its approximately 50 employees are sub-divided into billing staff, parking violation administrators, management, and other administrative personnel. The company also employs drivers for scanning vehicles (see Figure 5.5) and parking controllers who advance by foot, motorcycle, or car and who document a potential parking violation through taking pictures.

Dornier has partnerships with companies that perform the roles of **IT Integrator/Provider** and **Technology Vendor** for fulfilling their obligations. This includes the company that created and administers the smartphone parking application (Telpark) and the manufacturer of the street parking terminals (OLA).

City of Santander: Under the direction of the mayor and the city councillor for mobility, the administration established a parking manager function that oversees the contractual relationship with the service provider (Dornier). This individual is responsible for monitoring the service provider's performance and for addressing any parking-related issues that may arise.

Commercial Stakeholders: These are shops, restaurants, taxi drivers, and other businesses or individuals who are established within the IoT-supported parking area of the downtown core.

Associations/Interest Groups: Commercial advocacy groups have formed to represent the interests of business owners to the city and the public at large through informational campaigns. There are other (non-commercial) groups that promote their member's interests to the city or the general public. One prominent non-commercial interest group is "Cantabria con Bici" that promotes bicycle-friendly installations, such as bike lanes, and policies throughout the city and province.

European Commission (EC): The EC has made it a priority to improve the region's competitiveness through public funding. The EC's stimulus program, Horizon 2020, is tasked with improving Europe's economy, scientific/technology base, and industrial competitiveness through a wide-spread public funding initiative. The City of Santander and University of Cantabria actively collaborate with the EC on technology projects where the Smart City initiative is one cornerstone.

The interactions between individual stakeholders in the parking ecosystem can be broken down into detailed steps within several main process groups as described in the next section.

The parking stakeholders in Figure 5.9 map to the relevant perspectives of Morell's model (2018: 250) as follows:

Close observers: Entrepreneurs

Affected individuals: Users, City of Santander, Parking Service Provider (Dornier), Smart Santander Administration Telefónica Spain S.A. & NEC

Evaluators: City of Santander, Technology Provider (University), Commercial Stakeholders

Distant informed observers: European Commission

Sceptics and opponents: Associations / Interest Groups, Commercial Stakeholders

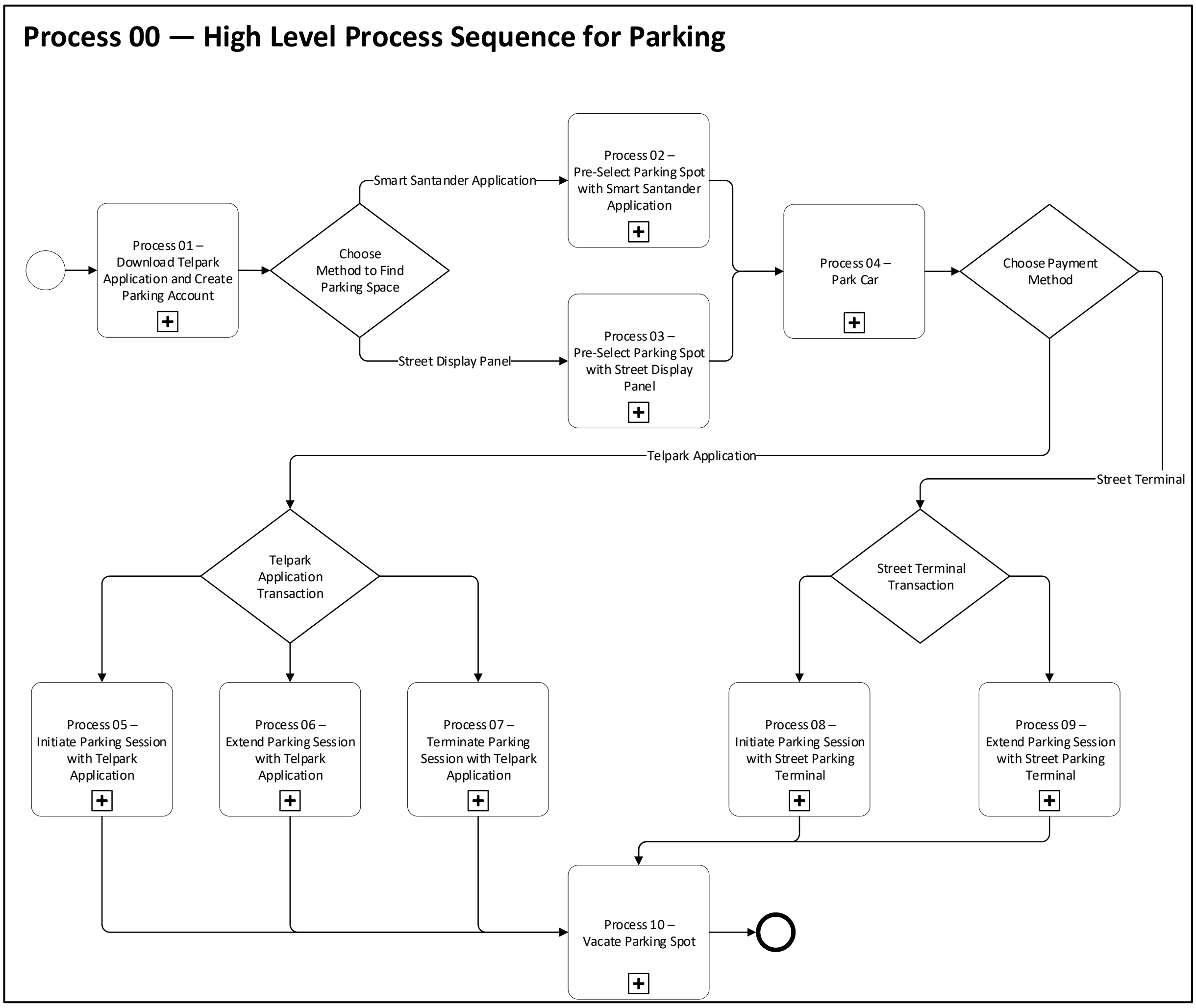
Intellectual or societal foundations: Associations / Interest Groups

5.6 Parking process maps

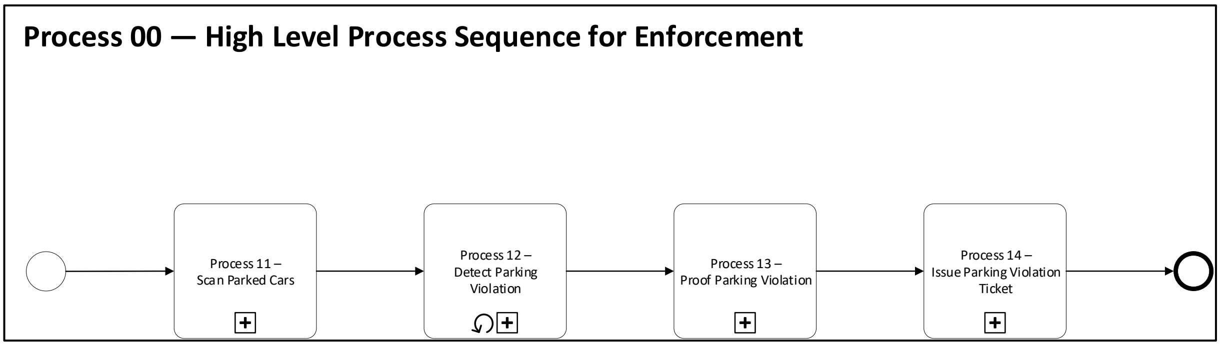
"Sensors don't change people's behaviour, but they help us understand it."
(Informant C3)

A prerequisite for identifying unintended consequences is to baseline what is expected, i.e., the intended consequences. At a detailed level, this translates into having process flows that capture the system's affordances. The following process maps were created to document the material logic and affordances of the system that then forms the basis to compare actual usage versus design.

The top-level map (Process 00) provides an overview of how all pertinent business processes build-upon each other across finding an available parking space via the smartphone application (Processes 01, 02, 03), parking the car (Process 04), using the Telpark parking application (Processes 05, 06, 07), using the street parking terminal (Processes 08, 09), and vacating a parking spot (Process 10):

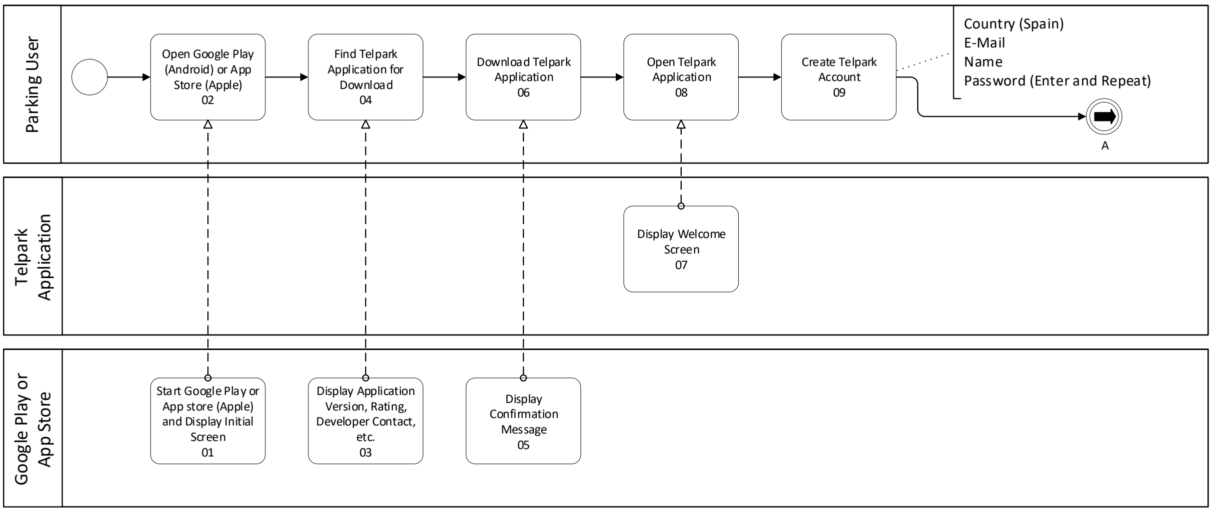


This top-level map (Process 00) then continues to define enforcement actions in terms of scanning parked cars (Process 11), detecting a parking violation (Process 12), producing proof of a parking violation (Process 13), and issuing a parking violation ticket (Process 14):

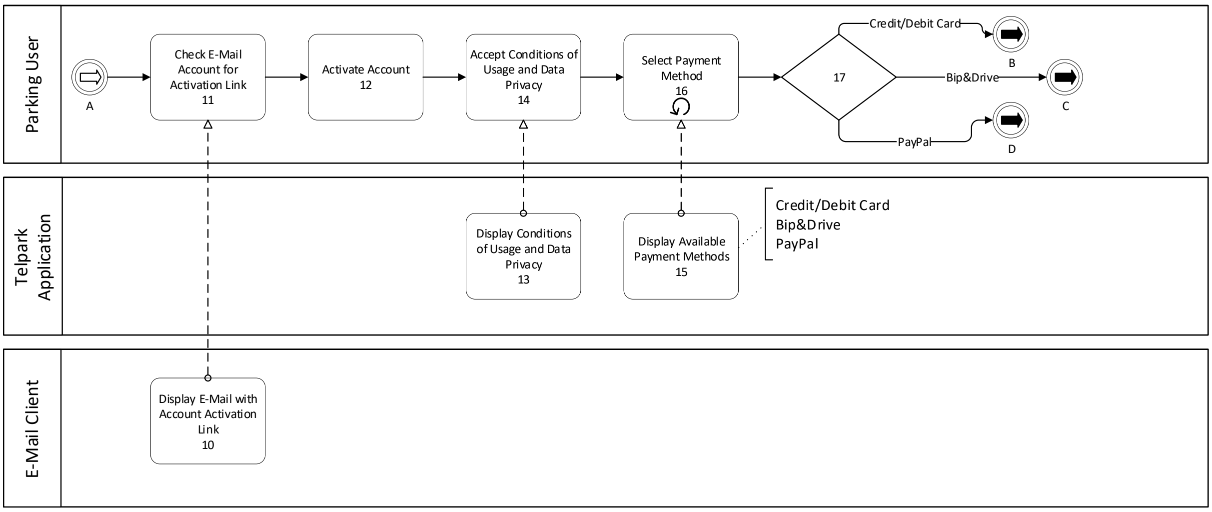


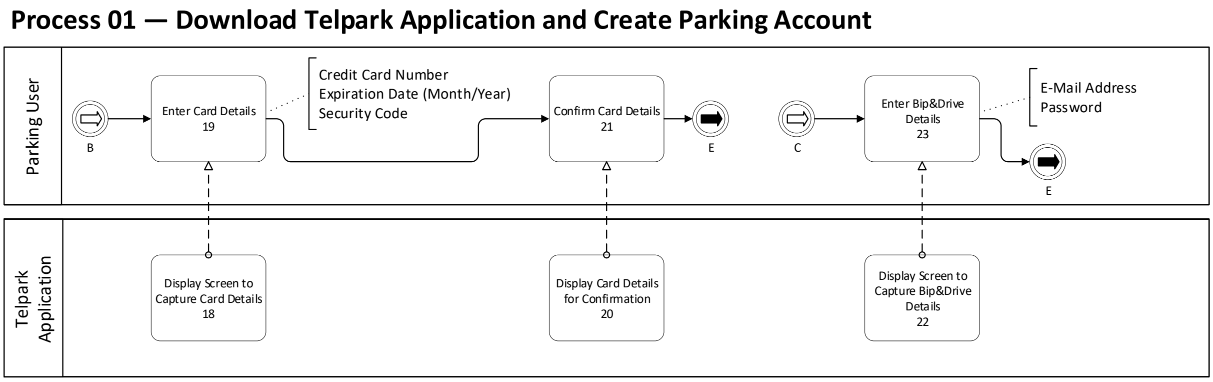
Each top-level process contains these detailed process steps:

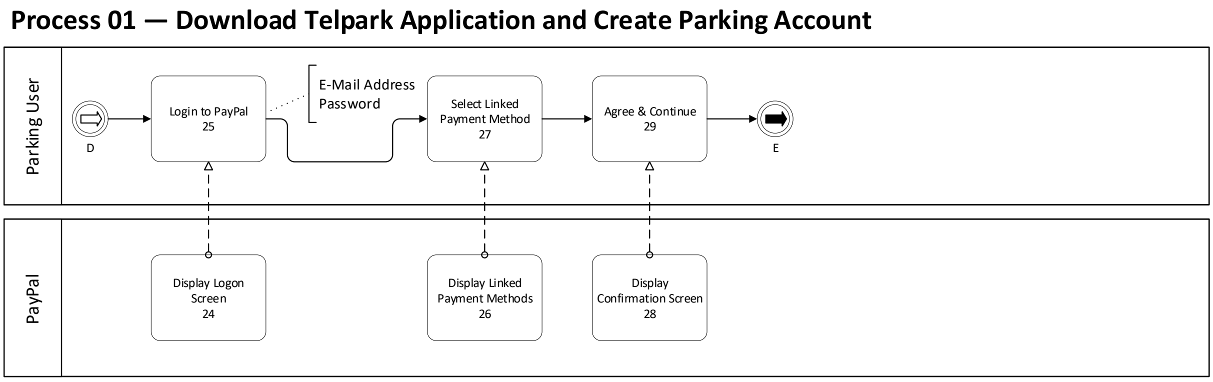
Process 01 — Download Telpark Application and Create Parking Account

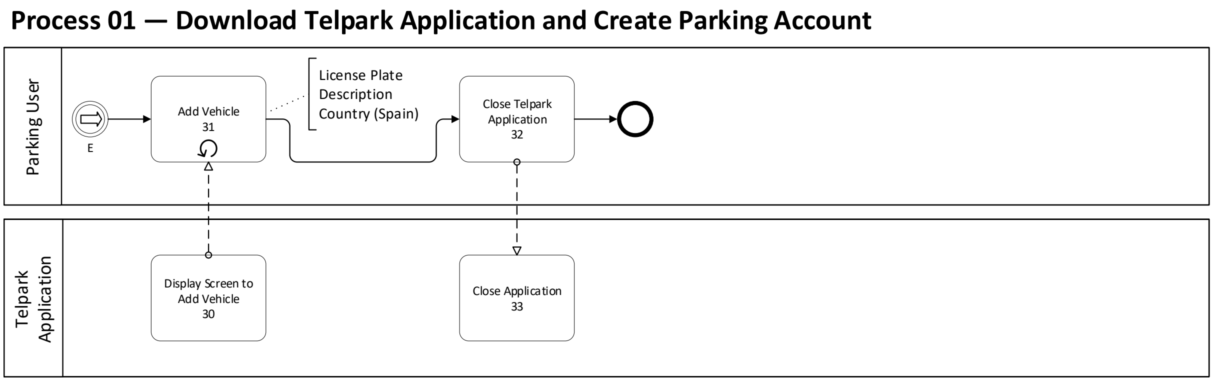


Process 01 — Download Telpark Application and Create Parking Account

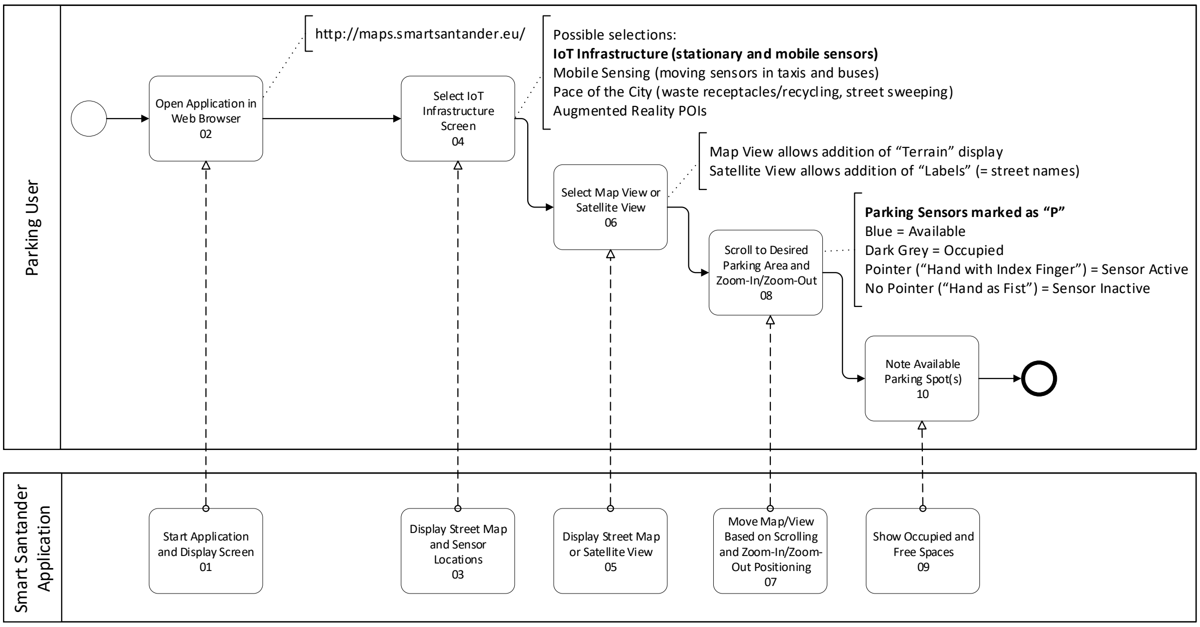



Process 01 — Download Telpark Application and Create Parking Account
Parking User
Telpark Application
B
Enter Card Details 19
Credit Card Number
Expiration Date (Month/Year)
Security Code
Confirm Card Details 21
E
C
Enter Bip&Drive Details 23
E-Mail Address
Password
E
Display Screen to Capture Card Details 18
Display Card Details for Confirmation 20
Display Screen to Capture Bip&Drive Details 22

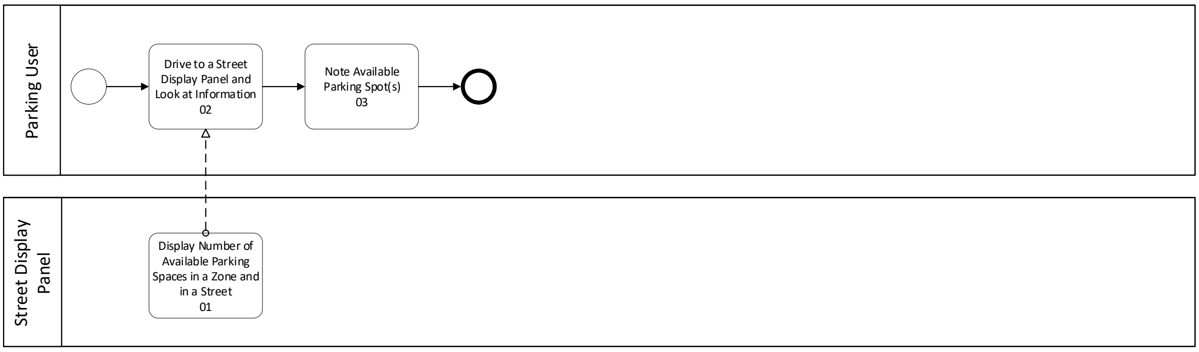

Process 01 — Download Telpark Application and Create Parking Account
Parking User
PayPal
D
Login to PayPal 25
E-Mail Address
Password
Select Linked Payment Method 27
Agree & Continue 29
E
Display Logon Screen 24
Display Linked Payment Methods 26
Display Confirmation Screen 28


Process 01 — Download Telpark Application and Create Parking Account
Parking User
Telpark Application
E
Add Vehicle 31
License Plate
Description
Country (Spain)
Close Telpark Application 32
Display Screen to Add Vehicle 30
Close Application 33

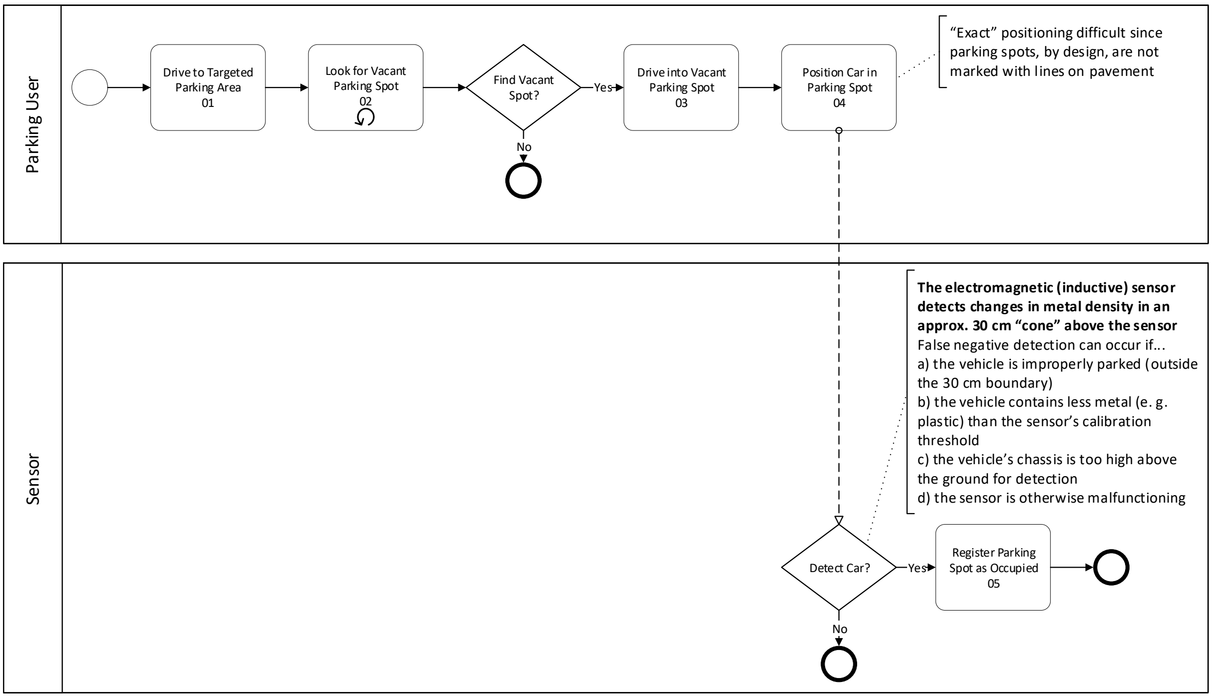
Process 02 — Pre-Select Parking Spot with Smart Santander Application



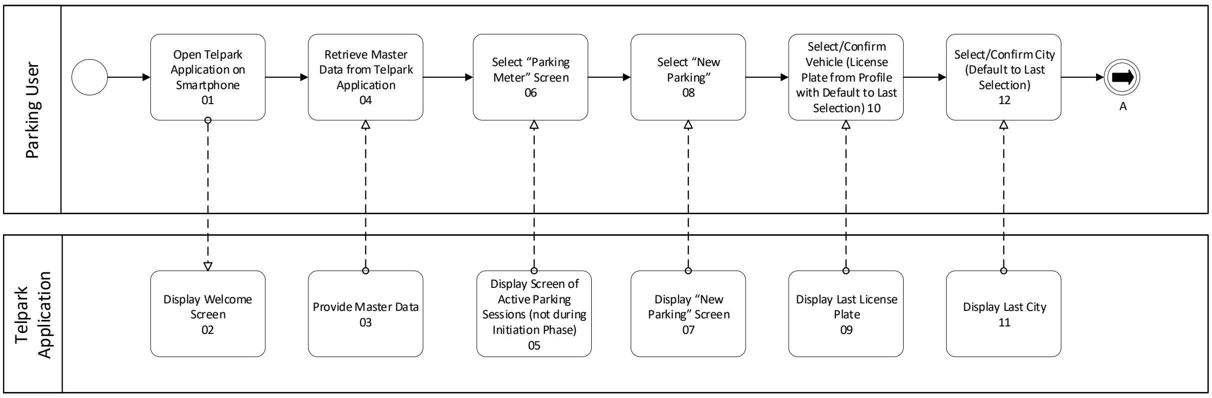
Process 03 — Pre-Select Parking Spot with Street Display Panel



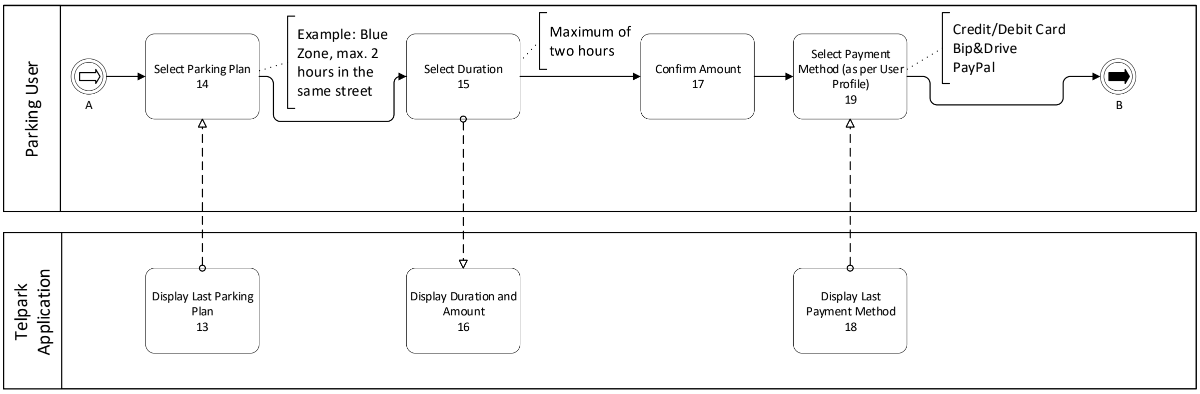
Process 04 — Park Car



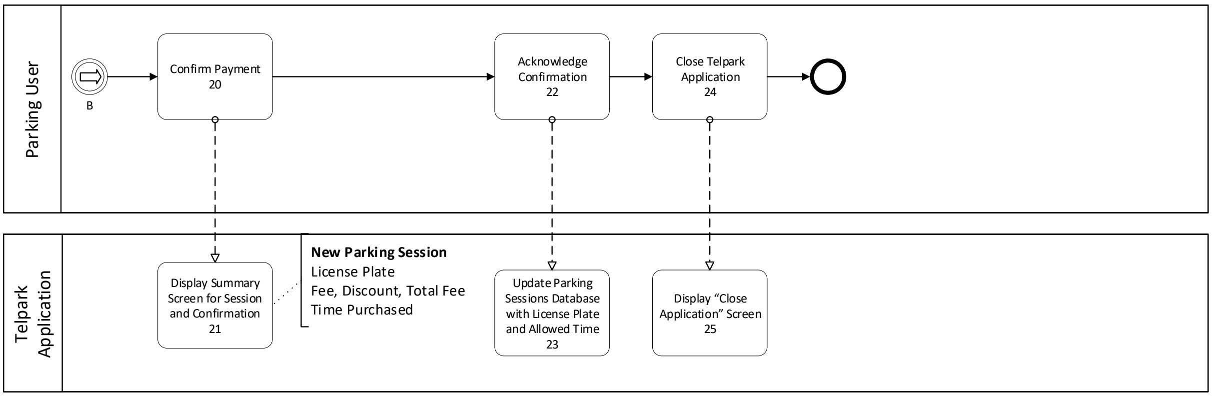
Process 05 — Initiate Parking Session with Telpark Application



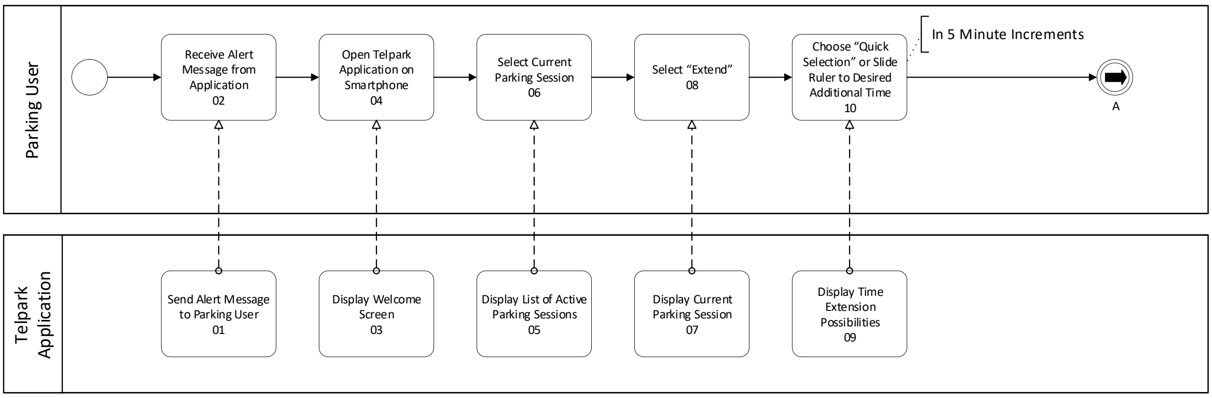
Process 05 — Initiate Parking Session with Telpark Application



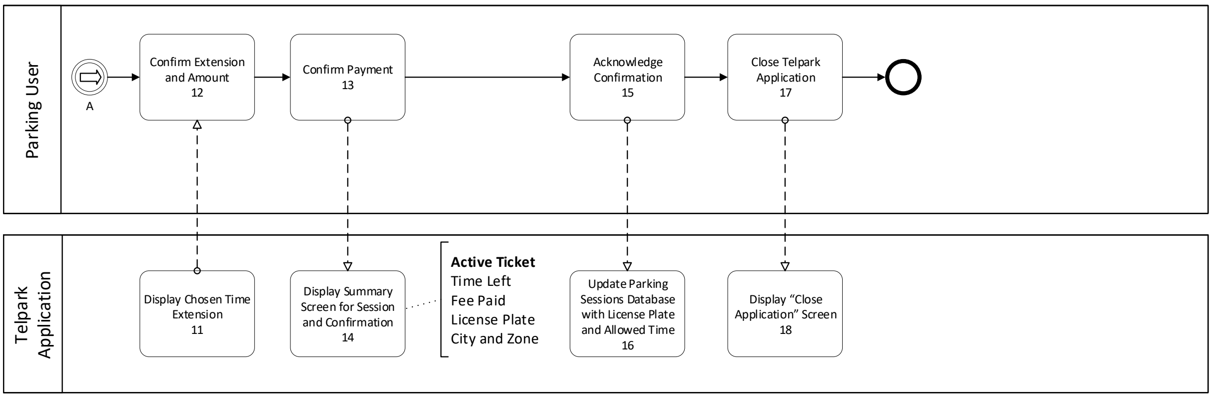
Process 05 — Initiate Parking Session with Telpark Application



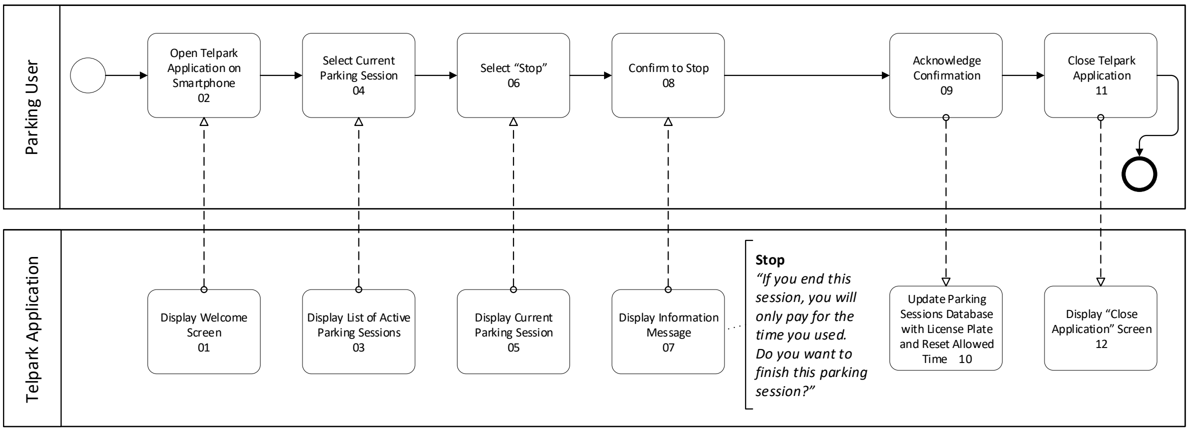
Process 06 — Extend Parking Session with Telpark Application



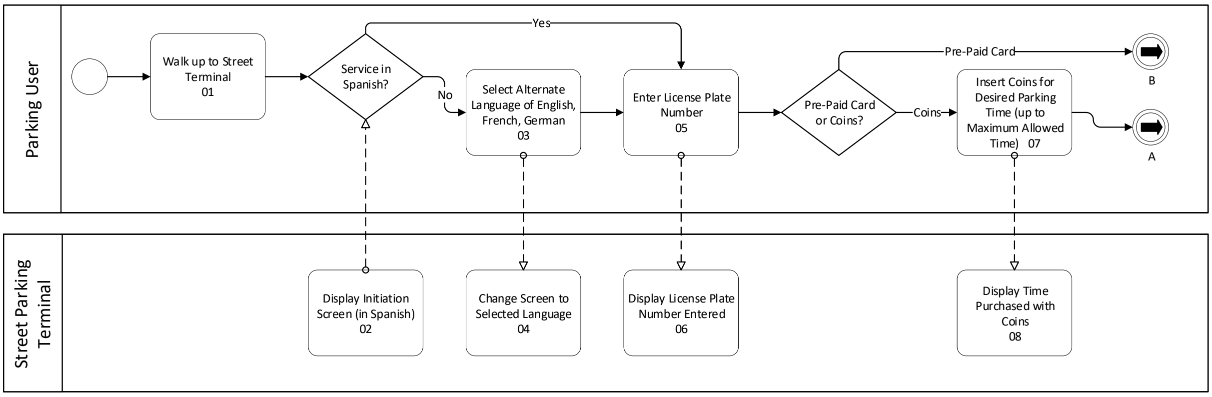
Process 06 — Extend Parking Session with Telpark Application



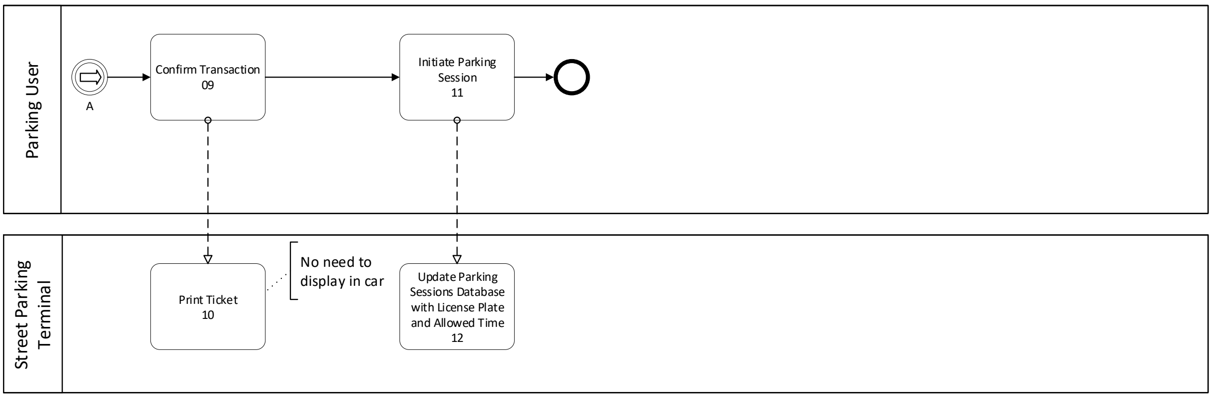
Process 07 — Terminate Parking Session with Telpark Application



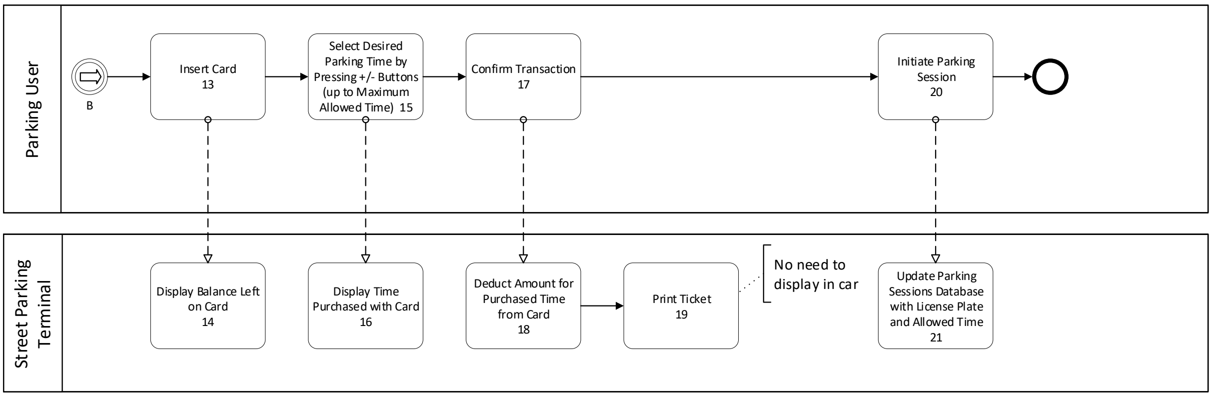
Process 08 — Initiate Parking Session with Street Parking Terminal



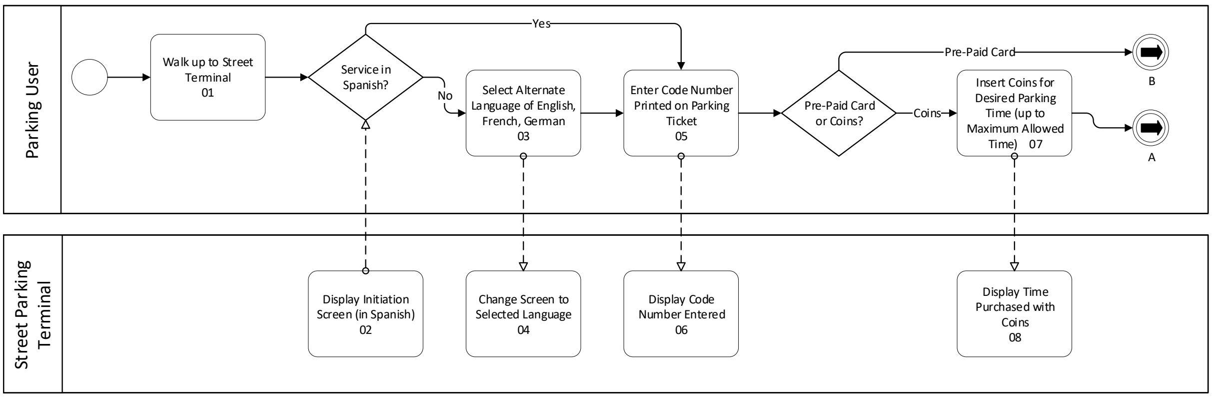
Process 08 — Initiate Parking Session with Street Parking Terminal



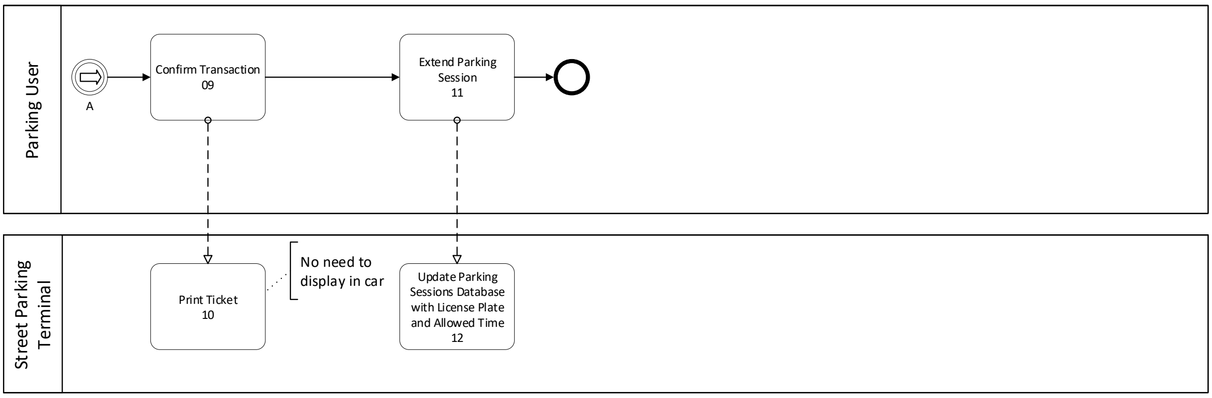
Process 08 — Initiate Parking Session with Street Parking Terminal



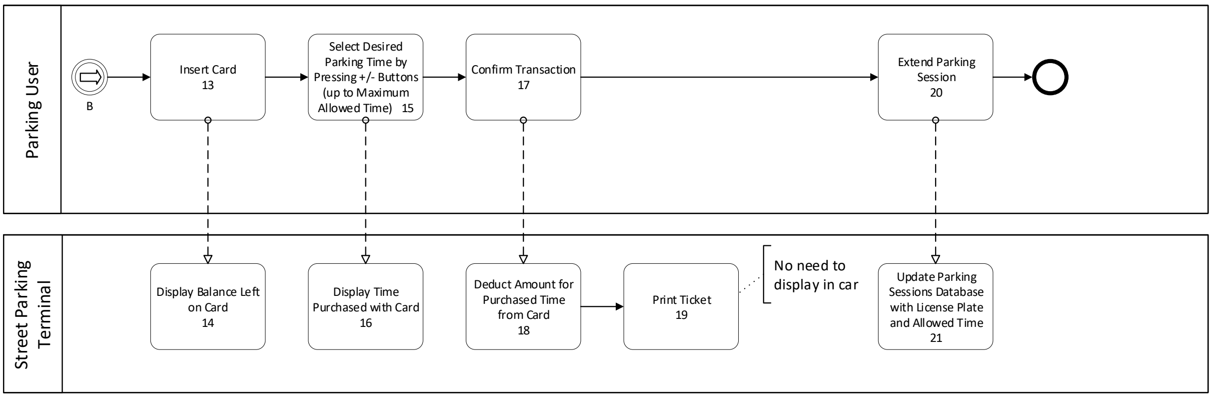
Process 09 — Extend Parking Session with Street Parking Terminal



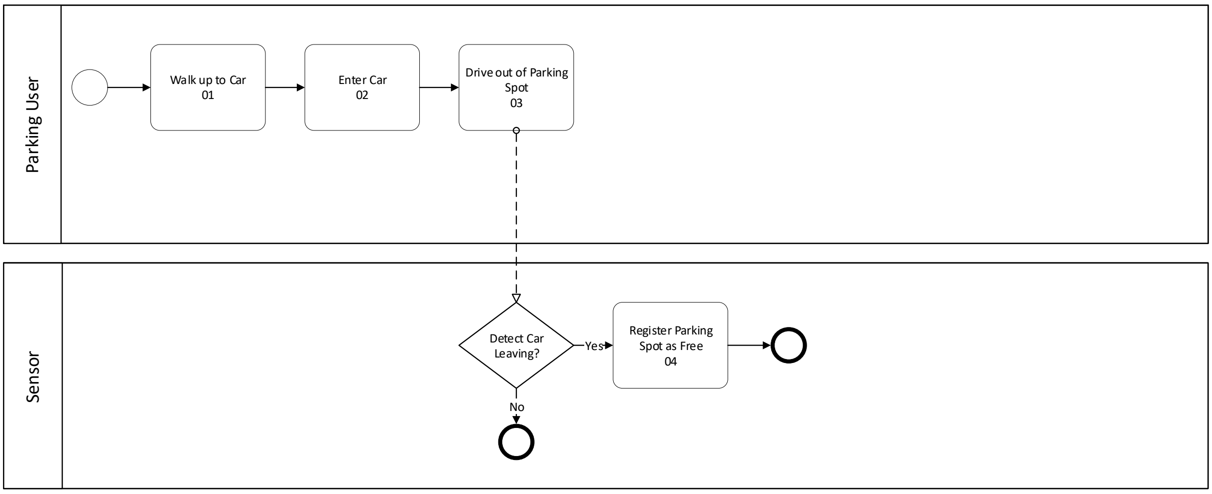
Process 09 — Extend Parking Session with Street Parking Terminal



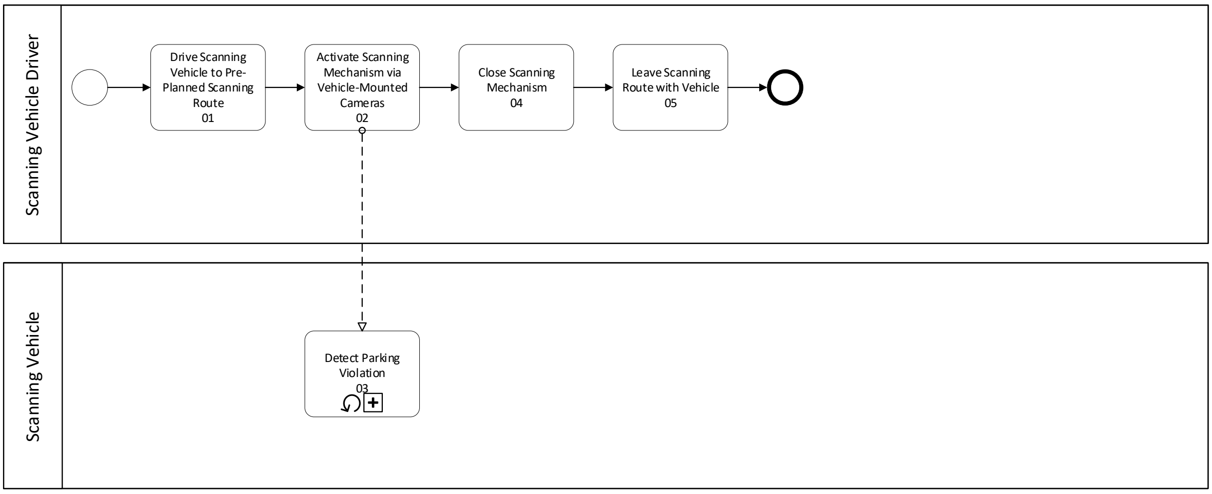
Process 09 — Extend Parking Session with Street Parking Terminal



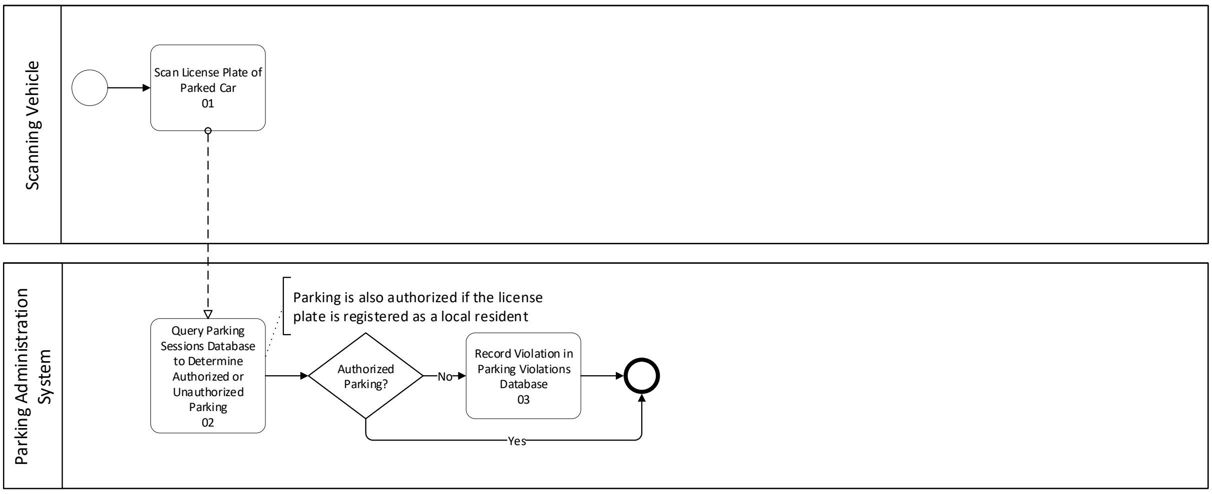
Process 10 — Vacate Parking Spot



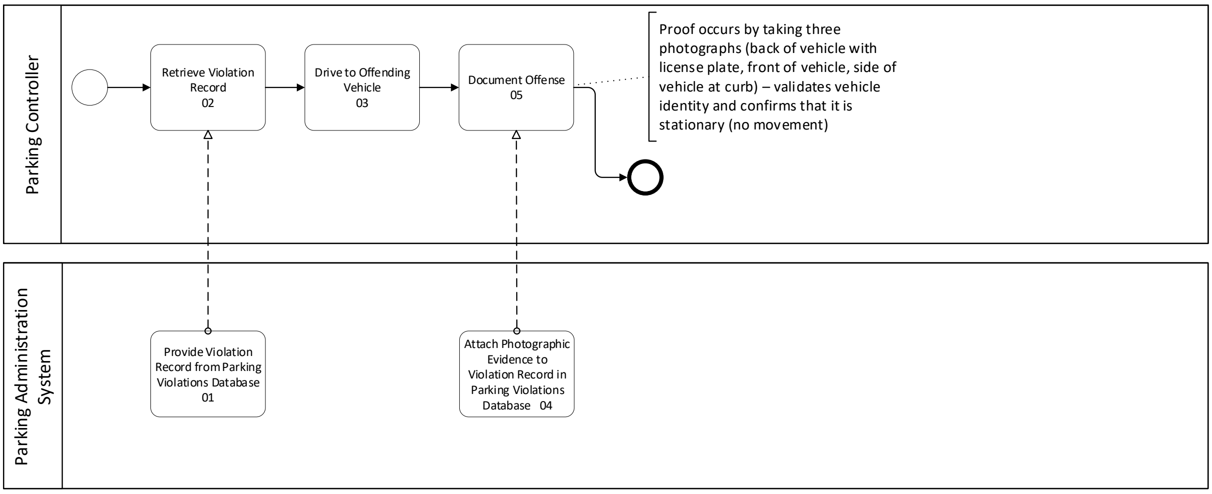
Process 11 — Scan Parked Cars



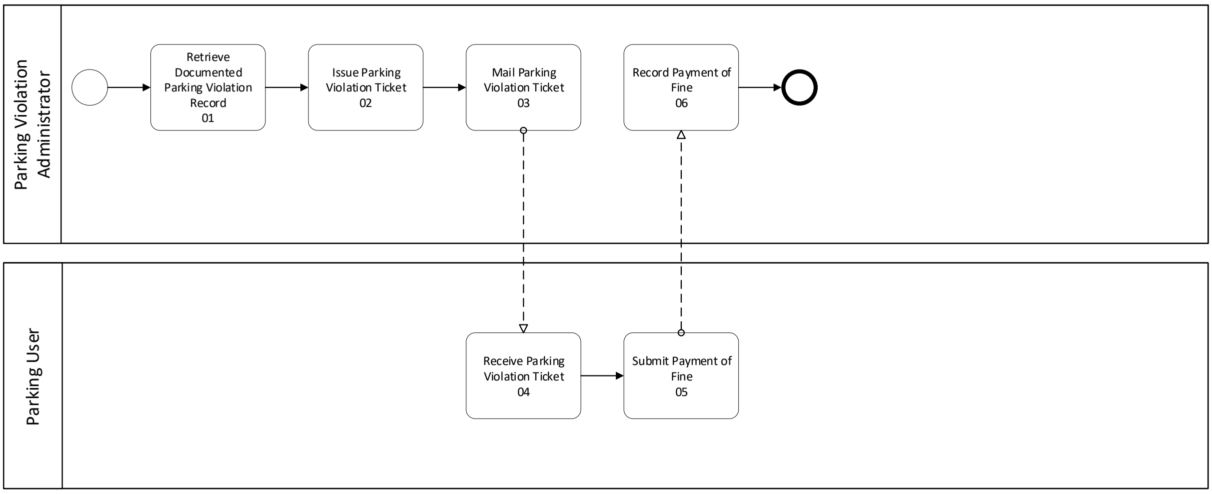
Process 12 — Detect Parking Violation



Process 13 — Proof Parking Violation



Process 14 — Issue Parking Violation Ticket

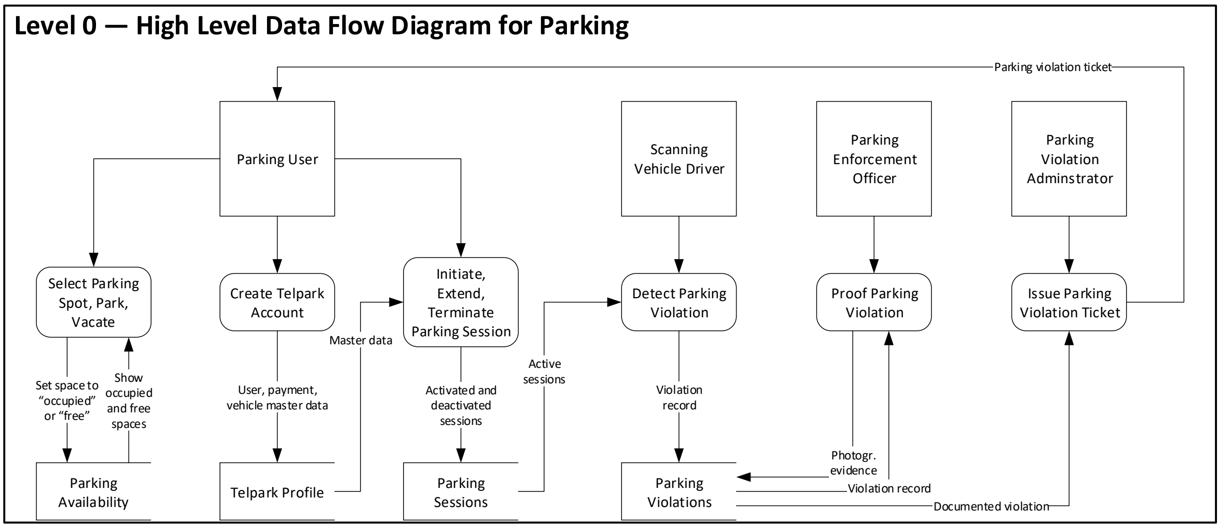


Each process generates or updates data at different steps. The next section captures these data movements within the IoT parking system.

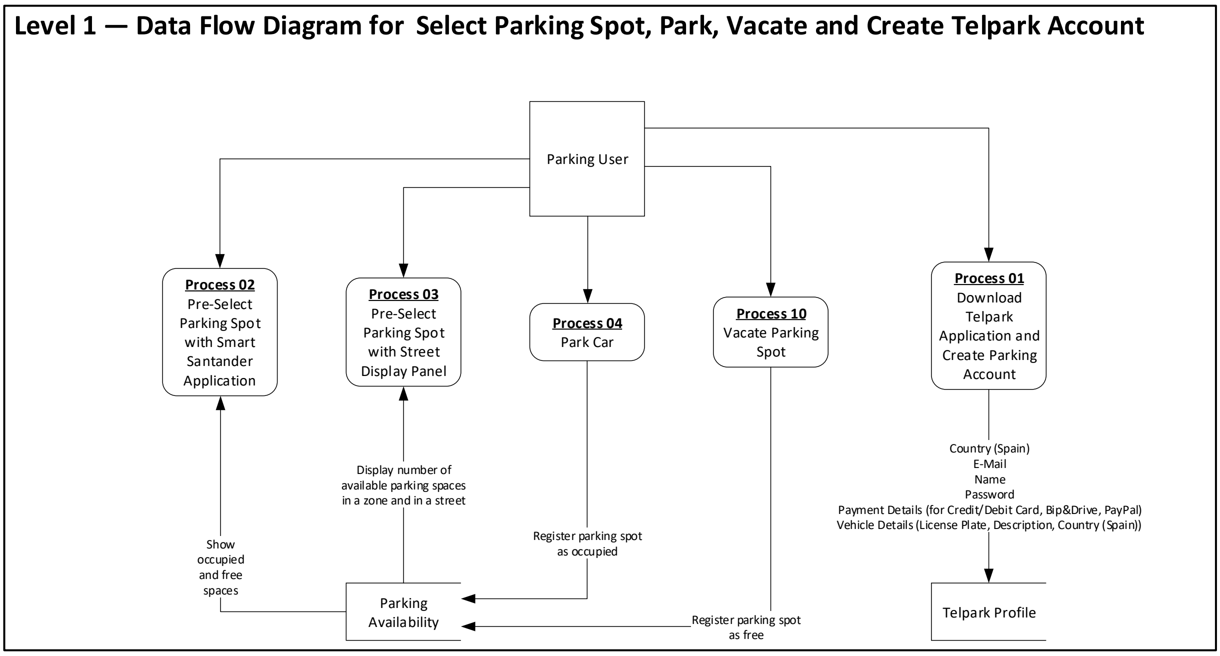
5.7 Data flow diagram

"You can't install a Smart City platform and say – ok, this is your toy, go play with it." (Informant C2)

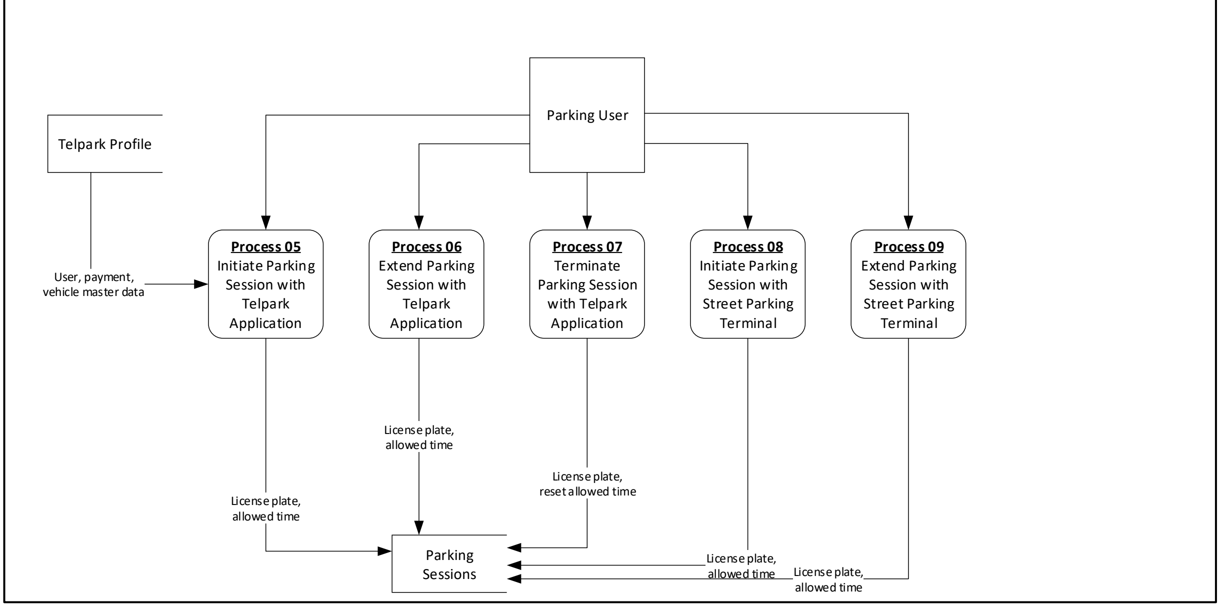
The Level 0 map provides a summary of database updates from finding a space, parking the car, paying via the Telpark application or the street parking terminal, vacating, and enforcement actions:



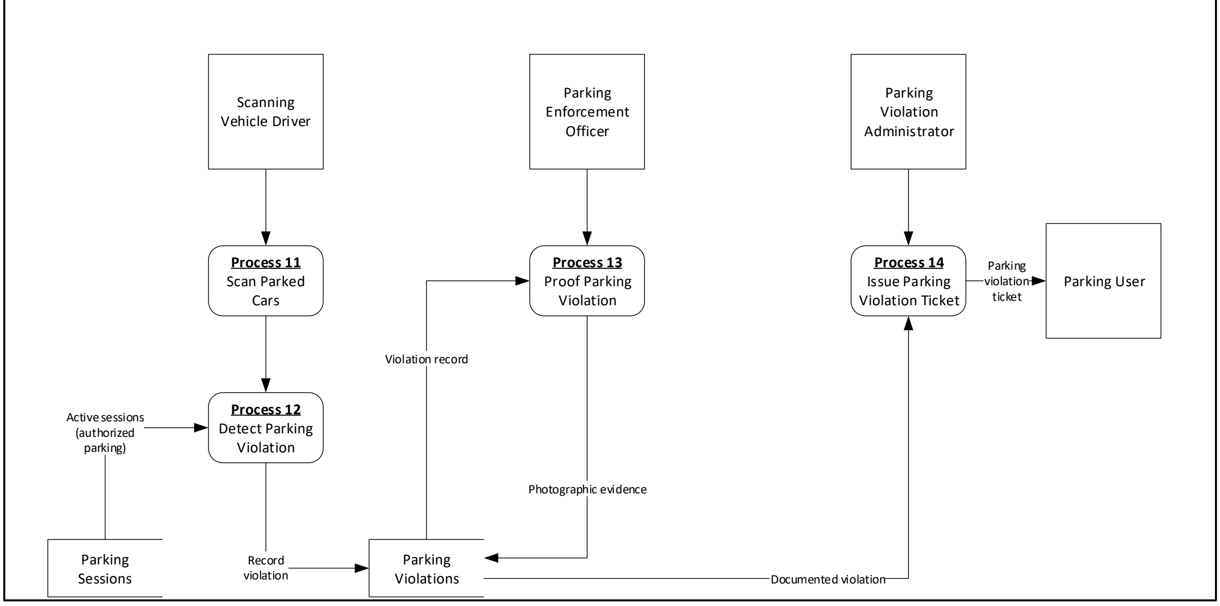
The next level of detail (Level 1) describes database updates for each of the 14 major processes:



Level 1 — Data Flow Diagram for Initiate, Extend, Terminate Parking Session



Level 1 — Data Flow Diagram for Detect/Proof Parking Violation, Issue Parking Violation Ticket



The next chapter describes the findings of the Santander case study.

6 Case Findings and Analysis

"Every particularity contains a generality." (Burawoy, 1985: 18)

6.1 Introduction to case findings

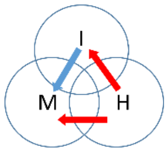
"It is not possible for a thing to act inconsistently with its own nature and remain the kind of thing it is." (Archer et al., 2013: 205)

This chapter extracts and analyses occurrences of unintended consequences (UCs) within Santander's automated parking solution. It does this by tracing detailed results derived from case study interviews through the corresponding arrows of the Sociotechnical Behavioural Framework (SBF). The analysis and derivation of findings is conducted in three parts:

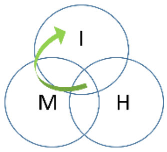
First, by describing the expected behaviour or outcome (the design) that is subsequently drawn out in the activated arrows between the framework's circles (coloured in blue). This part of the analysis answers the first part of the first research sub-question: *"What are the unintended consequences and their evidence based on intent and design versus use?"* Second, by capturing the realized behaviour or outcome that is found to be inconsistent or misaligned with the description of the (blue) design. The likely problem area causing such an inconsistency or misalignment is then highlighted by colouring the affected arrow(s) in red. Within this second step, a distinction is made between two basic types: Process related findings (Sections 6.2.14-6.2.30) link back to a specific process or lower-level process steps that was (were) not executed as previously designed. The analysis then continues by illustrating the design expectation that was not followed. Strategy related findings (Sections 6.2.1-6.2.13) are not attributable to a specific process but span generically across the entire parking solution concept. The deviation from the original high-level anticipation as to what a user is (or was) expected to do is being captured. Where data exists, this takes place in a time-phased fashion. This analysis cycle leads to UCs experienced and ultimately to potential reasons that are causing these consequences. With this, it answers the 'use' part of the first research sub-question: *"What are the unintended consequences and their evidence based on intent and design versus use?"*

Third, the analysis outlines the design change (to be) implemented by the City of Santander or Dornier, the parking automation service provider. If the change has not been implemented, but represents a potential future correction, it is highlighted as an opportunity for change. The change affects one or more circles of the SBF (Human Agency, Material Agency, or Interpretive Schemas). The arrow signifying the change is depicted in green.

This example highlights how the design foresees 'I influencing M' (blue) while the realized impact is an influence of 'H onto I' and 'H onto M' (red):



In this example, the sociomaterial entangled middle shows influence onto 'I' (green):



The case study interviews found 30 UCs that are described in detail in the next section. The results are sorted by first listing all strategy related findings that are more conceptual in nature. These start with fundamental issues experienced at the outset of the Smart Santander project, for example the resentment that resulted from not involving users early on and the fact that the project exceeded its cost estimate. What follows are more detailed process related findings that refer to specific process steps, such as when an expected parking space is unavailable upon arrival. Last in the detailed description are quality related issues that are not UCs per se and so they were not analysed further.

6.2 Detailed findings with link to unintended consequences

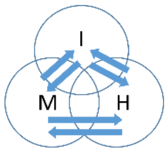
"Make it better or I want no part in this." (Informant R10)

6.2.1 Key finding: Citizen participation – UC: User non-involvement fostered resentment

6.2.1.1 Design

As McKeen and Guimaraes (1997: 133) commented, there has been significant research in the past on prerequisites for successful change management in system implementations. The single most important factor for success is active user participation from the beginning that is expected to lead to: 1) A more complete set of requirements. 2) Avoidance of unnecessary features. 3) A better understanding of the system. 4) More realistic user expectations about the system. 5) A reduction of conflict between users and designers during conceptualization and development. 6) Stronger feelings of ownership on the side of the users. 7) A decrease in user resistance to changes that are caused by the system. 8) A greater user commitment to the initiative and its success.

At the outset of the Smart Santander initiative, the project team envisioned for the city residents to fully and swiftly embrace the new functionality that represented – in the eyes of the project team – a significant improvement to the parking situation and to resident's lives. In terms of the Sociotechnical Behavioural Framework, the project team envisioned an equilibrium between rules and routines (I), the technology (M), and people who use the solution (H):

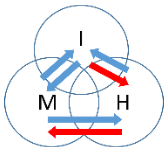


6.2.1.2 Realized behaviour and UC

During the initial roll-out, it became apparent that the new system, with its associated changes to people's routines, was not accepted by many of the city's residents and visitors. The Smart Santander project team conducted focus groups to learn more about the open resistance that had developed surrounding the implementation of the new system. The central themes that emerged through this feedback mechanism could be tied back to the circumstance that citizens were not consulted in the beginning and that the program was mostly advertised with its technological benefits. This lack of acceptance was the logical consequence of a poor system design change process. The lack of citizen participation had a direct negative impact on all eight previously listed facets by McKeen and Guimaraes (1997: 133). The Smart Santander parking project was spearheaded by technologists at the University of Cantabria and an IT/Telecommunications project team which predominately approached the initiative as a technology project and not as a citizen change/management effort.

One interviewee commented: *"You need to talk to the people in the streets before you put technology solutions in place. Ask them what are the problems that you face in the city and how could they be resolved? Afterwards, think about the technological solutions. Sometimes, the solution isn't related to technology. Sometimes it's just logical thinking or how you set up things in an urban environment. For me, the future of citizen participation is to first ask them what's wrong."* (Informant O1).

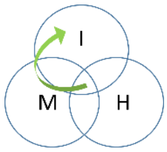
Results from the project team's post-mortem, that was conducted approximately six months after the initial implementation, confirmed that the problematic start could likely have been avoided through more up-front citizen participation and a dedicated change/management program to gradually introduce users to changed rules and norms when utilizing the new solution. Regarding the pathways of the SBF, the largest problem areas surround how humans (H) were using (or avoided using) the technology (M) and how new rules and routines (I) were not accepted by users (H):



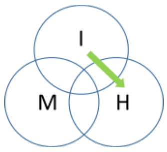
6.2.1.3 Design change or opportunity

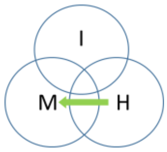
The project team wished that it had modelled new processes with actual users prior to going live. All use cases should have been tested in detail. While the initial problematic introduction of the new parking technology could not be 'redone', going forward, the project team utilized a more proactive approach in involving citizens for future functionality enhancements and its resulting change/management implications. The benefits of this improved approach became apparent when the city implemented Smart Waste Management and automated streetlighting in 2014, approximately one year after the rollout of the parking solution.

The setup of a Smart City demonstration centre (see Figure 5.10 in Section 5.5), with hands-on technology exhibits to allow visitors to understand and engage with technology, is a direct result from the citizen feedback received through focus groups conducted in 2013. The project team also published a brochure for children, consisting of cartoon characters, that explains Santander's Smart City concepts to visiting students. There is now a dedicated change management workstream in place to solicit users input into the design process. The Smart City team effected a change to the Interpretive Schema (I) that subsequently resulted in a better understanding of the solution (H) and also affected better interaction with technology (M):



In the first instance, there is a pathway from I to H, which is then followed in the second instance with a path from H to M:

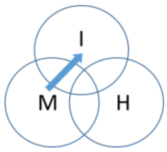




6.2.2 Key finding: Cost of burying sensors under pavement – UC: Project cost exceeds estimate

6.2.2.1 Design

Parking sensors are buried under the pavement for three reasons: The first is to avoid a tripping hazard. If the device were raised from the otherwise level road surface, even if only slightly, pedestrians could easily trip over it. Second, the layer of asphalt that is above the sensor protects it from the direct impact of the weight of a car. If the sensor were not protected as such, a substantial portion of the vehicle's weight would be concentrated on the sensor's plastic lid once the car was to drive over it. Third, the fact that the sensor is invisible to people protects it from potential wilful destruction or other attempts of tampering that may then interfere with its proper function. The characteristics of the sensor that necessitate its sub-surface placement are therefore threefold: 'not flat' which poses the tripping hazard, 'breakable' which requires protection from the excessive weight of the car, and 'attention creating' where it makes sense to hide it from people who may otherwise be tempted to interfere with it. These characteristics are part of the device's Material Agency that influence the designed placement through the M → I connection:

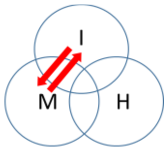


6.2.2.2 Realized behaviour and UC

During the initiative's planning and budget approval phase, the project team has greatly underestimated the cost that is incurred by placing sensors under the pavement. The anticipated cost considered were solely direct expenses related to breaking open the asphalt, placing the sensor, and resurfacing the affected patch on the street. The initial estimate (circle I) missed indirect cost related to road closures (circle M) that often must be accompanied by police-assisted traffic control.

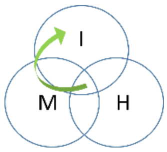
More importantly, the financial estimate assumed for the road work to take place only once at the time of the initial sensor placement. The first generation of sensors (installed in 2010) contained two 'always on' radios that caused excessive battery drainage and necessitated replacements after only a few months of usage. The second generation of sensors (installed in 2011 and 2012) is much more energy efficient, but battery replacements are still required after three to four years of use, thus prompting for additional road work to occur at least once during the life span of a sensor (estimated to be eight to ten years in total).

The limitation of the sensor's battery life has affected the Interpretive Schema of the financial plan disadvantageously within the same pathway (M → I):

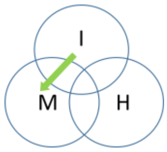


6.2.2.3 Design change or opportunity

After exceeding the initial cost estimate for sensor placement by over 70%, the city revised the planning parameters and process and now anticipates an average of 2.5 replacements for each sensor. The battery drainage patterns have also become more predictable, which aids in the ability to better estimate the amount and timeframe of the sensor replacement. This resulted in a change to the financial plan (Interpretive Schema):



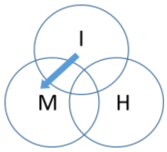
The increase in budget allowed for the procurement of more sensors in the subsequent time instantiation:



6.2.3 Key finding: Competition for parking spaces between visitors and residents – UC: General parking space unavailability

6.2.3.1 Design

The original parking plan was based on an estimate of 0.6 parking spaces per resident, which equals 1.67 residents per car; a ratio that is comparable to other densely populated cities in Spain and Western Europe. Santander experiences a large influx of tourists from approximately June to September and it was anticipated that the planned space would not be sufficient during these four months of crowded conditions. For the remaining eight months of the year, it was envisioned that 1,800 parking spaces throughout the city would be able to accommodate the city's residents as well as many out-of-town visitors during this non-peak season. The parking space design at large (circle 'I') controlled the provisioning of the number of parking spaces (circle 'M'):

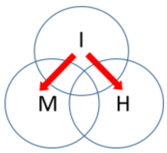


6.2.3.2 Realized behaviour and UC

In general, the original number of planned parking spaces proved to be too low even for the previously described non-peak time periods. There are residential areas in the city centre that also draw many visitors due to a concentration of restaurants and shops. This chronic parking space unavailability is particularly pronounced in these areas and has caused frustration among residents who live along these streets and resulted in a type of ‘competition’ between residents and visitors. One observer remarked that *“…it is seemingly a good system when you [as a resident] only pay 30 Euro for an annual parking pass. This theoretically allows you to park close to your house or apartment. The problem is when people pay this, but they then can’t park their car because all spaces are taken up by visitors.”* (Informant C1).

The general issue of unavailable parking spaces was underlined by several interviewees. One of them remarked: “*No, I mean [the system] works well. I wish there was always a parking space when I need it [laughing]. But there is never parking available. So, I use the bus or have my daughter drop me off…*” (Informant R13).

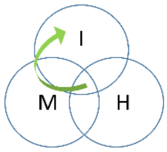
The design (I) of the overall number of parking spaces conflicts with the physical provisioning of spaces (M) as well as with the realized behaviour of residents and visitors (H) regarding the planned split between visitor and residential parking:



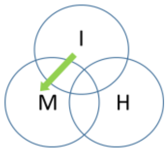
There is heightened sensitivity in the municipal government not to antagonize residents directly (as compared to visitors) since residents vote in local elections and visitors do not. However, there is still an impact when visitors stay away since it causes revenue shortfalls in shops and restaurants.

6.2.3.3 Design change or opportunity

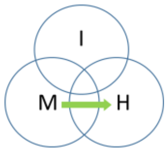
The city and parking space operator have been trying to resolve this problem since the beginning of the automated parking program, but with limited success. There are two moving targets that make planning extremely difficult: First, visitors who park their cars in one area fluctuate greatly and events such as store promotions or restaurant discounts cause wide swings in the demand for parking. In addition, annual parking passes that are purchased by residents vary from one year to the next so that demand for spaces and the split between visitor and resident parking can only be based on broad (and insufficient) assumptions. Where possible, the city has also attempted to add more parking spaces to alleviate the problem by relocating trash and recycling bins or other movable objects. Demand information based on human behaviour (H) together with available spaces (M) has therefore influenced the design (I) of the parking space layout:



In the next time-phased instantiation, this resulted in the provisioning (I) of more spaces (M):



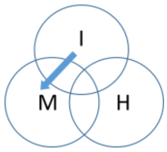
In the third instantiation, users (H) were able to park in the additionally provisioned spaces (M):



6.2.4 Key finding: Outdated technology causes citizen resentment when compared to other cities – UC: Expected parking space unavailable

6.2.4.1 Design

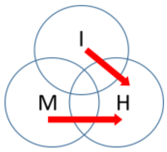
During the introduction of the smart parking solution, the City of Santander opted for the implementation of sensors as opposed to cameras to determine the status of parking spaces. The decision was in part based on Spain’s strict data privacy laws that make public usage of cameras difficult. At the time of implementation, it was also a financial feasibility question since cameras are significantly more expensive than sensors. Furthermore, it was not anticipated that the technological development of cameras would outpace the technological development of sensors. In retrospect, the city would arguably have benefitted from pursuing a camera-based system, but this was not the path pursued in 2012. The relationship between data privacy laws/cost constraints (circle I) with the technical decision to implement sensors (circle M) is depicted as follows:



6.2.4.2 Realized behaviour and UC

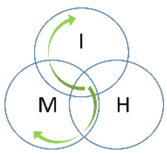
The residents of Santander are generally aware that their municipal parking system is based on outdated technology and many people seem to resent this substandard state. Informant R12, who uses the system several times per month, expressed this as such: "*The technologies are old. If you go to any other big city in Europe or America, what they implement today is much more advanced. What we have is old. It seems to me that camera usage is much wider now than before. And there are no more mistakes. If you have 50 parking spots, you could have 50 micro cameras installed with the latest technology and the system is much more reliable.*" Informant R12 answered the question of "if you could, what would you change about the parking system?" with the direct answer of "*switch to cameras.*"

The quality of the sensor-based system, the outdated method that it represents, and its substandard reputation (circle M) causes resentment among citizens. At present, the city decided not to change the technological setup (circle I). Both circumstances contribute to resentment and to people deciding not to use the system (circle H):

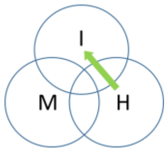


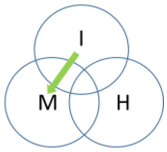
6.2.4.3 Design change or opportunity

The city will eventually have to switch to better technology for the system to survive. This has so far been prevented by a lack of funding. As of March 2022, the City of Santander is building a business case that would justify the investment. The solution is therefore two-fold and time-phased in that the business case (circle I) is expected to facilitate approval to upgrade the technology in a subsequent step (circle M):



From a time-phasing perspective, the first instance is H to I to affect the change in regulation and then I to M to implement the technology:



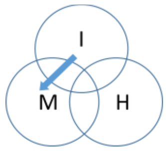


6.2.5 Key finding: Cameras are perceived as data privacy threats – UC: Expected parking space unavailable

6.2.5.1 Design

Santander has made inroads in the past with setting up cameras (without the ability to use them for facial recognition) for two main use cases: One is to obtain information about the flow of traffic at major intersections and thoroughfares, the second one is to count the number of people at the beach in the summer months. For the latter use case, the cameras distinguish indentations in the sand, as well as changes in colour, and through this allow the system to calculate the occupancy level for a particular area.

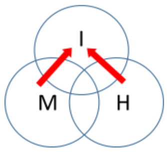
For parking solutions, cameras are by far the technically superior solution for determining the presence or absence of objects. The capability of a camera consistently exceeds results obtained by underground ferromagnetic sensors. The project team has developed the concept (I) that foresees switching the capability to detect cars in parking spaces from sensors to cameras (M):



6.2.5.2 Realized behaviour and UC

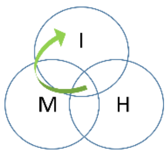
The sensitivities surrounding data privacy vary widely between countries and so they directly extend into Smart City developments. One expert interviewee commented that *"in Asia, for example in [South] Korea, privacy isn't a problem. Everybody knows that the Government is watching [as to] who is coming or going into a house. There is a willingness to give up privacy for an increase in security. Another example is South America, there, generally, you have a lot of security problems, but people also don't want to lose privacy. But the Brazilian Government has a lot of freedom to put security solutions in place. There is this famous panel in the control center in Rio de Janeiro. It's a large space full of hundreds of security monitors and personnel* *to operate the city. They don't care about waste management or water – they are all about security in the streets. This [having cameras on every street corner that are monitored by the police] is unthinkable in Santander and in Europe. In Santander, we don't have big security problems and we also don't like to give up privacy."* (Informant O1).

There is an ongoing major debate within the community on the usage of cameras and there does not seem to be a resolution any time soon. Furthermore, existing laws contribute to severely restricting the placement and usage of cameras. Many citizens are deeply concerned that the technical capabilities of camera usage (circle M) have an adverse effect on data privacy and – by extension – on the freedom of human interactions, movements, and personal routines. The inability to use a technically superior solution causes widespread adoption and trust issues among the user base. There is the availability of a technical solution based on cameras (circle M) that is not congruent with the regulatory framework (circle I). There is also the citizen's suspicion (attitude) that camera usage enables 'spying of the Government on citizens' (circle H to I):

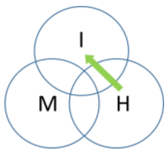


6.2.5.3 Design change or opportunity

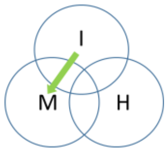
Cameras that were placed for the previous described use cases caused major debates about data privacy within the community. The activities in this field revolve around the interaction between laws and human perception. Ongoing educational efforts to explain the design (I) to users (H) is complemented by city officials (H) lobbying for a change in the regulatory framework (I) that would allow future camera usage:



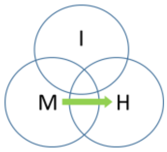
The current lobbying occurs in time instantiation cycle 1 and is expressed as a link from H to I in the SBF:



It is expected that this subsequently changes the design that allows for the technology's implementation (I to M):



The project team is anticipating that the technology will ultimately be regarded as 'non-threatening' and will cause a change in people's attitude regarding their data privacy concerns (pathway M to H) in a third time instantiation:

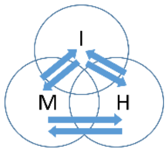


6.2.6 Key finding: "Free rider" syndrome – UC: Anonymity of system is conducive to cheating

6.2.6.1 Design

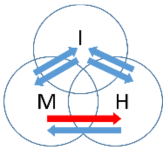
The basic objectives of the parking system are simple: the city charges for the convenience of parking close to shops and restaurants, drivers pay the fee for being allowed to park in a spot, the existence of a charge (and the threat of a fine) incentivizes users to only stay in a spot as long as they need to stay there, and the city and parking administrator are reimbursed for the cost of putting the solution in place. Based on the feedback from most designers, administrators, and users, the system works well overall. There are contingency measures in place to deal with exceptions in the system, for example people not paying for parking or people overstaying the allowed time where the parking space is then not available for other users.

In its design, the system foresees an equilibrium between the rule set (arrow I to H) with a feedback loop to modify rules over time (arrow H to I), the design (arrow I to M), technical advancements that may influence the future design (arrow M to I), and humans using the automated solution according to its design (arrow M to H and arrow H to M):



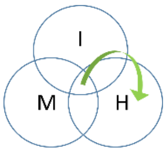
6.2.6.2 Realized behaviour and UC

Upon the introduction of the new system, the city experienced a certain kind of resistance that expressed itself in a *free rider syndrome*, referring to the social science concept of a market failure when beneficiaries of a communal service underpay for it or do not pay at all. According to a project observer, the practice of avoiding paying for parking increased upon the introduction of the automated system. According to the observer, *"it is difficult and takes a lot of guts to cheat a parking attendant by not paying him what he is due and to just drive away"* (Informant C3). This psychological barrier is much lower when people deal with an automated solution. Here, the part that is being taken advantage of is not represented by a person who would have a negative and disapproving reaction to somebody who tries to circumvent the system. As such, the anonymity of the automated solution (M) negatively affects human behaviour (H):



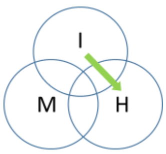
6.2.6.3 Design change or opportunity

The city embarked on an educational campaign, by utilizing flyers and posters, to appeal to the sense of fairness among its residents. It has been difficult to measure the effect of such an 'honesty campaign' in a more precise fashion since no baseline measurement(s) exist. Anecdotally, the administrators of the parking solution noticed a general improvement in people's behaviour:

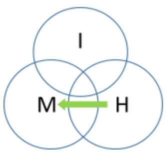


Members of the project team expressed that it would have been beneficial to anticipate such reactions ahead of time so that messaging and education could take place proactively.

From the viewpoint of time instantiations, the educational campaign is depicted as an influence from arrow I to H:



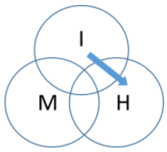
This subsequently changed people's behaviour (circle H) when it comes to the action of payment (circle M):



6.2.7 Key finding: Payment requirement during COVID-19 lockdown viewed as unfair – UC: Perceived unfairness changes behaviour

6.2.7.1 Design

The requirement to pay for parking is in effect on weekdays from 10am to 2pm and from 4pm to 8pm. The paid parking time on Saturdays is from 10am to 2pm. During these times, the parking duration is limited to a maximum of two hours – parking is free of charge during all other times. If the user parks during the paid-parking time, the design of the system (circle I) requires the user (H) to render payment. This can occur either via the Smart Santander app or the street parking terminal:

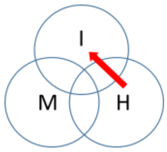


6.2.7.2 Realized behaviour and UC

The City of Santander did not alter this rule during the COVID-19 lockdown. Offices, shops, and restaurants in the city centre were closed intermittently during 2020 and 2021, resulting in very few people visiting the city centre. There were time periods where hardly a car was parked in the otherwise congested business district. People wanting to park their cars were still expected to pay for parking Monday through Friday, 10am to 2pm and 4pm to 8pm, and Saturdays from 10am to 2pm. This was considered unfair by Informant R7: "*It's not fair what's happening with COVID. Back in the time when parking wasn't available easily, it was OK to pay for parking. With this, people only stay the time that they need to and then they make the space available again for other people. Now that there are fewer cars here, why do I have to pay? If I just park, I get a ticket, but the rule isn't fair. The municipality should make the price almost zero when there are many spaces available.*"

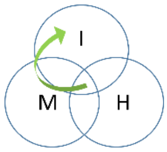
This sentiment has resulted in changes to people's personal routines that later, after the lockdown was lifted, did not revert to pre-pandemic practices. Once people became used to, for example using alternate transportation, the new habits would remain, and the overall pre-pandemic parking revenue has not (yet) reached its previous level after the lockdown ended.

In the SBF, the new personal routine of avoiding paid parking is expressed through circle H that is now conflicting with the city's expectation of parking usage (circle I):

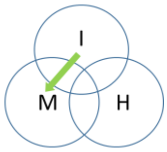


6.2.7.3 Design change or opportunity

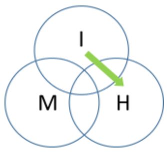
The city could alter this rule (circle I) and provide a cost reprieve to visitors and residents. The city administration was severely understaffed during the COVID-19 lockdown periods, and it appears that the reduced staff was unable to invest time and resources in entertaining such a rule change:



This change would first be expressed through the rule change (I) affecting payment through the machine (M):



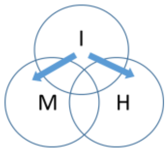
After the rule (I) has been in place for users to internalize the change, the modified rule would affect people's perception (H):



6.2.8 Key finding: Change/management of sensor installation – UC: Disruption of routine causes frustration

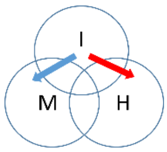
6.2.8.1 Design

The City of Santander's Road Construction department embarked on the sensor installation work in 2012. At that time, the city did not conduct a general information campaign to alert the public as to the work that was taking place. The expectation on the side of the city planners had been that the effort would be largely transparent to residents. This stemmed from the circumstance that previous sub-asphalt sensor prototypes were installed at the University of Cantabria's parking lot where ongoing vehicle and pedestrian traffic was not present. Therefore, neither the city planning team, nor the public expected the level of difficulty and disruption that accompanied the sensor installation effort. The anticipation was a balance between the plan (I) to install the sensors (M) and the Human Agency (H) of dealing with the impact of this multi-week initiative:



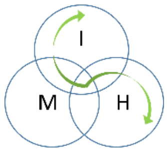
6.2.8.2 Realized behaviour and UC

Citizen's routines were significantly disrupted due to the sensor installation. The work to break through the asphalt was more involved than originally anticipated and city workgroups had to be fenced off to protect workers from bypassing traffic. This in turn slowed down traffic and prompted drivers to take alternate paths in an establishment of new routines. One substantial unexpected side effect of this change in traffic patterns was the loss of business for shops and restaurants along the sensor installation routes. Since side streets that received the traffic were not set up to accommodate an increase in traffic volume, congestion became a chronic multi-month problem in the city. There was an increase in air pollution as idling cars waited to pass through narrow thoroughfares. The situation was exacerbated by the fact that the first generation of sensors was not waterproof and so the work to place sensors had to be conducted twice. This essentially doubled the time-period, during which city traffic was severely disrupted, to over 30 weeks. While the need to install and replace sensors is not a consequence resulting from human behaviour, the lack of a defined change management design and the negative perceptions that were attached to the program did cause the unexpected consequence in human behaviour (route I to H):

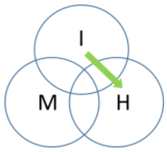


6.2.8.3 Design change or opportunity

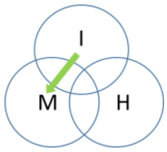
The project team did not take immediate actions to alleviate the situation. One project participant expressed that this activity was *"lost in the heat of the battle".* The team reflected on this issue in the project post-mortem exercise and decided to institute two actions: Whenever possible, move roadwork into the early morning hours where this activity would be minimally disruptive to drivers. As a second learning, the team decided to communicate, in advance to citizens to alert them to upcoming disruptions. Both actions resulted in changes to the Interpretive Schema, meaning the process design as to when to conduct roadwork as well as up-front communication of such roadwork:



In a time-phased view, the explanation (I) to citizens (H) occurred first:



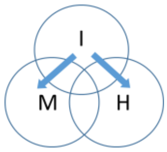
Which was then followed was the change to the road (M) based on the updated design (I):



6.2.9 Key finding: New parking system was co-introduced with new (higher) fee structure – UC: Unrelated fee increase caused user resentment

6.2.9.1 Design

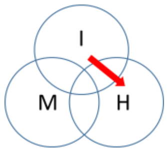
The city had been working on two separate initiatives: The introduction of the sensor-based parking system within the inner part of Santander's downtown area and, simultaneously, on a revision of the fee structure for parking across the entire city. While the two initiatives are unrelated, they were nevertheless rolled out at the same time. As expected, the increase in parking fees received much criticism from drivers, which did not really concern the project team that worked on rolling out the new parking solution. The current design (I) directs the system (M) and influences the user's perception (H):



6.2.9.2 Realized behaviour and UC

In the minds of many citizens, the two initiatives were linked, and the negative reception of parking rate increases transferred onto the (independent) project of introducing the new parking solution. In the words of a project participant *"it caused a citizen revolt"* (Informant C2).

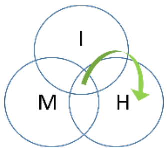
Many residents who had previously registered their home addresses and received significant discounts were unhappy. The new fee structure that came into effect severely curtailed rebates for resident parking. The new rule set (I) negatively (and surprisingly) affected people's disposition (H) with regards to the new parking solution:



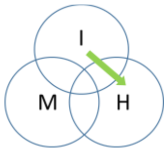
The perception of the cost increase, and the strong negative emotions around the parking solution in general, caused a drop in system usage.

6.2.9.3 Design change or opportunity

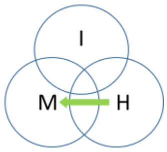
After the project team realized that the negative perception of the fee revision directly hindered the adoption of the new parking solution, city planners embarked on a rapid and widespread communication campaign that emphasized the independence and benefits of automated sensor parking. The key message in this communication was the fact that the automated parking system can save money and therefore minimize the effects of the rate increase. The system does this in two ways: 1) Through dynamic pricing that incentivizes drivers to park in less crowded (and cheaper) areas, 2) Through billing for the actual time parked when using the Smart Santander mobile phone application. Through the application, the user does not have to pre-pay a fixed parking time that she or he may not end up using. For purposes of the framework, the communication campaign changed the human disposition and personal routines connected with the system:



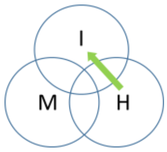
Or, as a first step:



In a second instantiation, people's attitude (H) changed where usage of the system (M) increased:



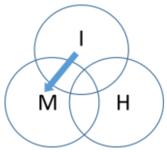
In a third instantiation, citizens (H) lobbied for changes to the new fee structure that was simultaneously implemented (I):



6.2.10 Key finding: Interaction of automated parking solution with previously defined parking zones – UC: Users unfairly pay too little or too much for parking

6.2.10.1 Design

Each one of the 30 existing parking zones in the city of Santander consists of an area of approximately four to eight streets. Historically, parking zones have been used for a variety of administrative functions – i.e., setting fixed parking rates for a zone or assigning parking enforcers to one or more zones. At the time of the system's roll-out, the city planners simply did not anticipate a conflict between old and new use cases for parking and their impact on zoning. For the purposes of the SBF, parking zones are a simple set of rules (circle I) that guide pricing configurations within parking meters (circle M):

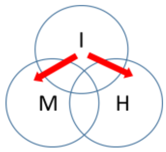


6.2.10.2 Realized behaviour and UC

When rolling out the new parking system, the city did not revisit the existing delineation of parking zones that exist within the city centre. Most importantly, these zones are used to set dynamic pricing, where an increase in parking demand elevates the price for parking – and vice versa. This is conducted to incentivize drivers to park (or not to park) in certain areas, and during certain times of the day, with the aim to equalize the overall parking volume. Over time, as businesses open and close, and practices shift within and across zones, some of these artificial geographical boundaries have become meaningless and the distribution of these zones no longer makes sense. For example, 'Zone A' may be largely comprised of a quiet residential area. At its border, in proximity to 'Zone B' but still within the boundaries of 'Zone

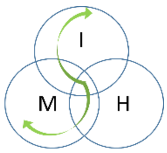
A', there is a small city area with shops and restaurants and correspondingly heavy volume of traffic and parking demand. The rest of this commercial area extends further into 'Zone B'. During dynamic pricing adjustments, 'Zone A' is recalculated based on the average parking volume, which is low overall, since it encompasses the much larger portion of a residential area. The calculated parking rates are likely not in line with the traffic volume in the commercial region, i.e., the lively area, of 'Zone A'.

It would be preferable to reset both zones so that each is dedicated to their predominant traffic and parking patterns. For example, 'Zone A' with only the residential part, and 'Zone B' with only the commercial part. If this split were implemented, pricing would remain relatively stable in 'Zone A' because of the steady (and low) parking volume and 'Zone B' would recalculate more often based on fluctuating traffic and parking volumes. The system is currently out of balance from two perspectives: The zoning rules (circle I) sub-optimally control how dynamic pricing is applied in the system (circle M) and the same rules (circle I) are not in line with people's actual routines (circle H) of parking their cars:

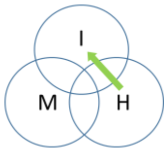


6.2.10.3 Design change or opportunity

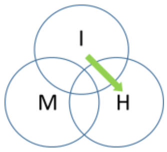
The city, together with the parking administrator, is still conducting an analysis where data is being collected to suggest a re-zoning based on actual conditions of cars and their driver's parking practices within the city. There has been considerable opposition to the re-zoning proposal since businesses have a vested interest in keeping parking charges low to entice more visitors to the area. Not redrawing 'Zone A' is the preferred outcome for business owners in that zone since the co-presence of a quieter residential neighbourhood keeps parking cost down. Associations of restaurant and shop owners have traditionally lobbied against this rezoning effort. If the city succeeds in this endeavour, the interpretive schema with zoning rules (circle I) could be reset and subsequently change dynamic pricing rules within the system (circle M):



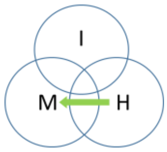
Therefore, the rule modification occurs first:



Where it is then followed by the new rule influencing people's perception:



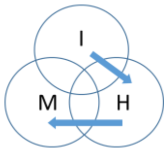
And, lastly, a likely change in parking behaviour:



6.2.11 Key finding: Managing competition-related conflict among solution providers – UC: Service provider's proposals are unrealistic

6.2.11.1 Design

With the implementation of the Smart Santander platform, the city provides for an open exchange across various stakeholders. City departments, citizens, universities, and companies (entrepreneurs) have access to almost all raw data from various services that the city collects. In the case of established solution providers as well as entrepreneurs, these companies can develop their own applications based on these data that is made available to them. The idea is to foster a competitive environment between these entities for continual innovation and the introduction of new technology and solutions. This set of innovation practices, originating from circle I, positively influences the disposition of solution providers (circle H) to create new solutions (circle M):

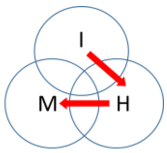


6.2.11.2 Realized behaviour and UC

The creation of this competitive environment led to tensions between the city, service administrators, citizens, and solution providers, which is largely caused by the practice that the European Union financially subsidizes technology creation for entrepreneurial start-up companies. The previous direct link between citizens and their city council members no longer exists and the power balance shifted. A city employee commented *"[…] it has changed the way that we manage the relationships here in Santander. Before these initiatives, the city council had the relationship with the citizens. But now, it is a triangle where we develop pilots, then there are the companies that are participating in the project, and the university. [All of them] are working together with the municipality. Of course, the citizens are an important part of these projects. Depending on the projects, we involve the citizens from the very beginning. In some cases, the citizens propose their own projects, but the relationship between the different stakeholders has been transformed a lot and, of course, not everyone in the city has the knowledge and has been involved in those projects."* (Informant C1).

The possibility of receiving 'free money' from the European Union's technology acceleration program has resulted in a lot of companies putting forward multiple proposals and attempting to out-bid each other. It has also led to intense lobbying by companies among the city's residents to support their proposal. Another city administrator remarked that *"[…] people come to the municipality with the question of 'how do we make this a European project?' And… everybody knows everybody else, and everybody wants to be popular. [People and companies] want to be the 'star' of the Smart City."* (Informant C2).

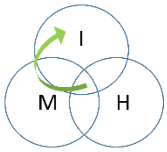
The incentive of European public subsidies (circle I) created a highly competitive environment where all potential contributors (circle H) try to be first in line to provide solutions (M):



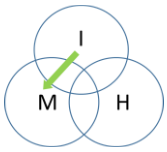
6.2.11.3 Design change or opportunity

The city has addressed this counterproductive behaviour of service provider candidates by introducing a better governance process. The municipality issues 'Requests for Proposals' (RFPs) with a firm date by when the reply to a public tender is due. Individual candidate companies then describe their proposed solutions and complement it with a cost estimate. If a company does not submit by the deadline, the proposal is not considered. The governance committee consists of city administrators and the Santander Program Management Office and is supported by a group of technical experts who opine on the feasibility and anticipated quality of the proposal. The group works closely with the city's Finance department to assess the credibility of financial estimates. This offsets companies putting forward artificially low bids to secure the contract and then overcharge during the construction and implementation phases of the project.

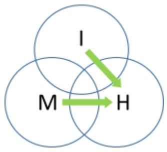
Another practice that Santander implemented is conducting the selection process approximately twice per year. If a company was not successful during one selection round, there is still the possibility to be picked during the next iteration. The introduction of this more rigorous rule set had the desired effect on human behaviour, which in turn led to better designs:



The change in Santander's selection practices (I) increased the quality of the solutions (M):



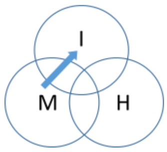
In the next instantiation, the increased solution quality coupled with support for entrepreneurs enhanced the solution provider's 'attitude' towards the process:



6.2.12 Key finding: Road construction curtails profit of service provider – UC: Unscheduled roadwork decreases profit

6.2.12.1 Design

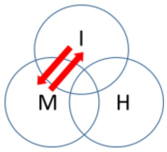
The payment model for the service provider is set up where the parking administration company (Dornier LLC) keeps all revenue generated from the public and pays a monthly fixed fee to the City of Santander, with the delta between these two amounts constituting the service provider's profit. Their cost base is relatively stable with fixed cost being comprised of personnel expenses, electric scanning vehicle consumption and asset depreciation, maintenance, and other fees related to administration. Any reduction in revenue directly translates into a reduction in profit and the business case was originally calculated by applying a monthly average number of parking sessions that is adjusted for seasonality. The assumptions that were made by the planning department regarding the total number of parking spaces (M) directly affect the plan for revenue and profit (I):



6.2.12.2 Realized behaviour and UC

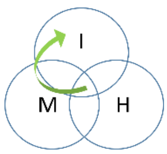
Dornier, the service provider, has virtually no influence over road service work that is scheduled and conducted by the city. The activities that the city undertakes and that curtail the availability of parking spaces, as well as the timing of these activities, is outside of Dornier's control. This was not realized by the company at the start of the ten-year engagement when the revenue and profit projections were calculated.

This circumstance has, over the years, been a point of repeated tension between Dornier and the city administration. As an example, in 2017, the city undertook 11 individual unscheduled maintenance events that reduced Dornier's profit by approximately 8% for the calendar year. Given the fact that the contract with the city is a low-margin engagement, this represented a significant shortfall in what Dornier expected to earn in profit in 2017. From an SBF perspective, the rules that were instituted (circle I) directly constrain the availability of parking spaces (circle M) and therefore curtail the actual revenue and profit (circle I):

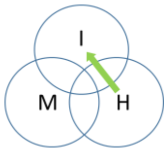


6.2.12.3 Design change or opportunity

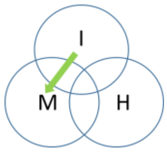
The city administration and the service provider increased the frequency of their operational planning meetings from a monthly to a bi-weekly schedule. The meeting participants previously did not discuss higher level agenda items and did not address availability questions for individual parking spaces. Both parties now put forward such tactical matters in the planning meetings, which allows Dornier to more frequently adjust their revenue and profit forecasts. Dornier has also taken a more active stance with the city to influence the timing of road maintenance activities and advocate for a combination of work projects/closures where it makes sense. By doing this, sensors and parking spaces become unavailable during a time that allows for multiple activities to be bundled together, which minimizes the total off-time for parking spaces when observed over a longer time horizon. When possible, road service work is now also taking place during non-peak parking hours. The activated STMB pathway is a change in the rule set (circle I) of the framework by improving the coordination of roadwork activities, protecting revenue and profit plans, and reconciling goals that are at times in conflict with each other:



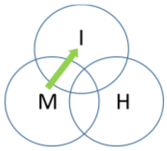
First came the change of the rule set (I) by city planners:



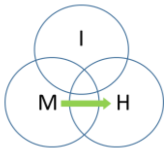
Where the improved rules (I) subsequently increased the availability of the sensor framework (M):



After this was accomplished, the widened availability of the parking system (M) increased revenue (I):



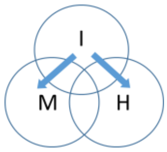
What followed this result in a subsequent time instantiation is easing of tensions between the city and the service provider (H):



6.2.13 Key finding: Difficulty for service providers to deliver solutions bundled with technology – UC: Smaller pool of potential service providers

6.2.13.1 Design

Prior to Santander's deliberate transition into a Smart City, service providers were able to exclusively focus on the delivery of a product and the actual service. Historically, these companies had built their expertise around trash collection, supplying water or electricity to Santander's citizens, or in handling parking administration. This changed with the introduction of the Smart Santander data platform and the aim of collecting data and making it available for usage across many stakeholders. Traditional waste management, water, electricity, or parking administration service provider companies are now expected to put in place data feeds from their systems into the Smart Santander platform. This opens the complexity of having to deliver technology in addition to pure service delivery. Different companies are at different technical maturity levels and the introduction of the requirement had far reaching changes to the public tender (bidding), selection, and implementation processes. The Santander Smart City Program Management Office created a comprehensive requirements document that specified what data fields, and with which frequency, need to be provided to the platform. The technical mechanism for the data transfer is a ReST-API, a Representational State Transfer – Application Program Interface, that is constructed as a web service. It allows the standardized integration of sensor data into an application. The Program Management Office also has technical experts on staff who work with solution providers during the scoping, analysis, design, construction, testing, and implementation phases of projects. The interpretive schema (circle I) contains the technical design for a solution that influences circle M. Simultaneously, the design requirements also affect the abilities, skills, and personal routines of developers (circle H):

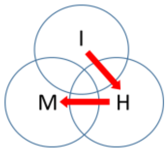


6.2.13.2 Realized behaviour and UC

The impact of the change for service providers to take on the role of technicians was, and still is, significant. First, it altered the landscape of companies who participate in public tenders. Several companies who historically provided services to the city of Santander, and who did so with very good results, were no longer able to compete. These companies were not able to acquire the required technical capabilities in-house nor were they able to secure an effective partnership with a sub-contractor who could have provided the technical components of a project.

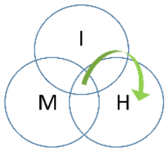
Second, two companies attempted to adapt to the new reality and proceeded to construct the technical solution. In addition, another company partnered with a technical provider to complement their service offering with the required ReST-APIs to send the data. However, the three companies underestimated the complexity, and the related cost factor that built-up over the duration of the project, and all three initiatives failed.

The central reason for the failure, as underlined by a post-mortem analysis that was undertaken with two of the three providers, has been the technical requirement (circle I) that could not be accommodated by the company's management or staff (circle H). In addition, the staff could not transpose technical knowledge (or the lack thereof) onto the solution (M):

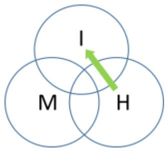


6.2.13.3 Design change or opportunity

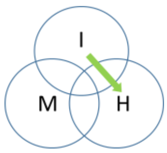
The feedback from city administrators underscores the importance of continually refreshing the design documentation and other written artifacts. The team recently added a newly constructed Frequently Asked Questions (FAQ) document. Aside from these actions and being available to solution creators to answer questions and provide technical advice, there is little that the team feels that they can add. The Santander Smart City Program Management Office has invested in four technical analysts who are able to support solution providers during all phases of a project. The level and frequency of assistance can be tailored to the technical knowledge level of the client company. The alleviation of the problem therefore lies in providing training and coaching to technical analysis and managers within the service provider companies (circle H):



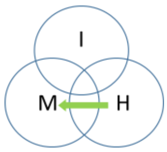
In the first instantiation, the team (H) created the FAQ document:



Over time, the documentation increased the technical abilities of some solution providers:



In another instantiation, the increased skill set led to better technical solutions:



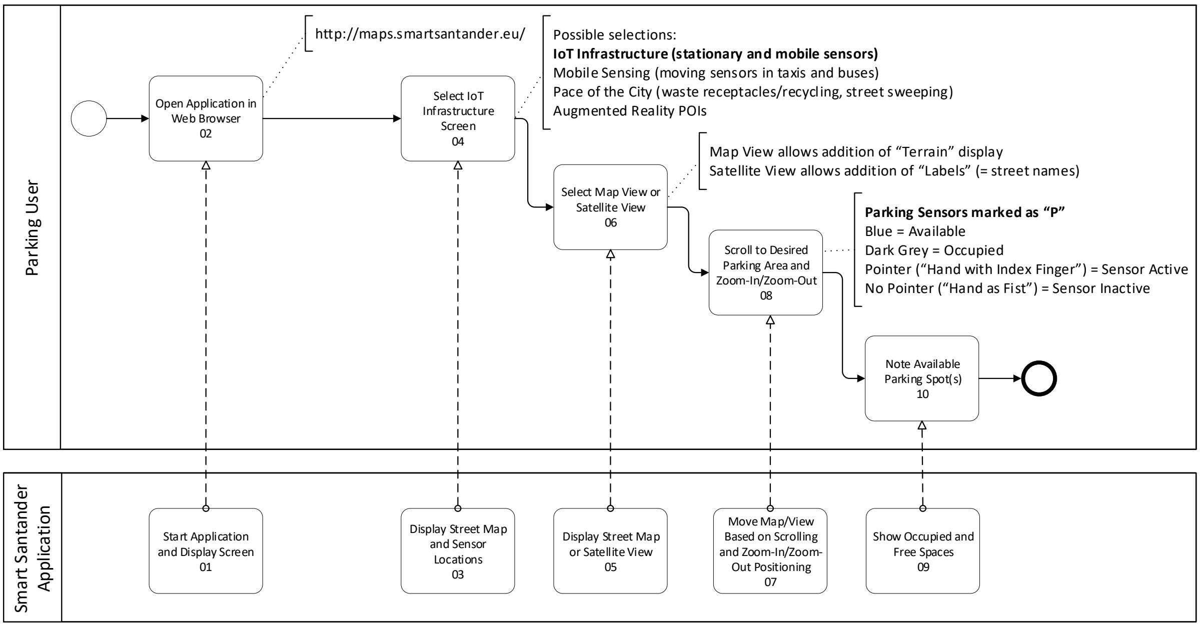
Which subsequently led to an increased competitive pool (I) and an improvement in the confidence of solution providers (H) to create a better product:

6.2.14 Key finding: Smart Santander parking spot selection impossible while driving – UC: Expected parking space unavailable

6.2.14.1 Design

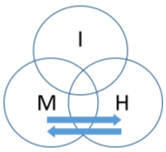
The Smart Santander application to view parking spot availability can be used on any mobile device:

Process 02 — Pre-Select Parking Spot with Smart Santander Application



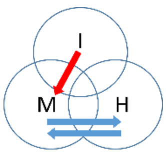
The user initializes the application in a web browser (Steps 01 and 02) and selects the display of the street map and sensor locations (Step 03). The application then displays the menu items of 'IoT Infrastructure' (for stationary and mobile sensors), 'Mobile Sensing' (for moving sensors that are placed in taxis and buses), 'Pace of the City' (for waste and recycling receptacles and street sweeping), and 'Augmented Reality POIs' (Points of Interests). At Step 04, the user chooses the 'IoT Infrastructure' screen that subsequently leads to a choice between 'Map View' or 'Satellite View' in Steps 05 and 06 that can be further enhanced by selecting the 'Terrain' display under 'Map View' or the 'Labels' display (street names) as an extension of the 'Satellite View' menu item. The user can then position the map via dragging it across the screen and zooming-in or zooming-out as desired in Steps 07 and 08. Parking sensors are marked as 'P' on the map with a colour coding that indicates their availability status with 'blue' as 'available' and 'dark grey' as 'occupied'. The symbol of a 'pointer', symbolized by a hand with an extended index finger, confirms that the sensor is functioning (active) and the absence of such a ‘pointer’, symbolized as a formed fist, signifies that the sensor is not functioning (inactive). The application thus provides an overview over functioning and non-functioning sensors whereby the former category is subdivided into available and occupied sensors in Step 09. The user is able, through Step 10, to select the street parking spot as the desired parking location.

The SBF pathways indicate that the system provides availability information to the user (M → H) and the user selects a desired parking spot from the available suggestions (H → M):



6.2.14.2 Realized behaviour and UC

For a driver who is in the car alone, it is nearly impossible, and certainly unsafe, to look for potential available parking spots while operating the vehicle. It is possible to interact with the application prior to commencing to drive or while stopping the vehicle to do so, but it still presents a lack of convenience. Smart Santander does not allow for reserving parking spots through the application and solely shows availability data as of the present moment. Thus, a space that may have had the indication of ‘available’ prior to beginning the journey, may subsequently be occupied by a different driver, and further diminish the convenience of pre-selecting parking spaces. The system does not provide a solution to obtain up-to-date parking information on a near-real time basis. This negative affordance is rooted in the design of the technical solution and is expressed as follows in the SBF framework:



The design in pathway I → M does not support the functionality that would remedy the problem. The formal norm is depicted as:

Whenever < user intends to select a parking spot via the Smart Santander Application

If < parking space symbol is indicated as ‘blue’ (available) on the selection screen

Then < user

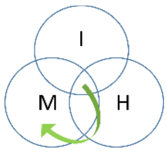
Is < must

To Do < decide which parking space is selected to attempt to park the car

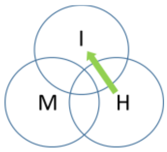
This highlights the design limitation in that there is no possibility for the user to reserve the parking space until s/he arrives at the spot so that the accessibility of the space can be reasonably guaranteed. Furthermore, the user is unable to obtain up-to-date parking information on a near-real time basis. Aside from a lack of convenience and an erosion of trust in the system, i.e., when the envisioned parking space is not available upon arrival, there is an increased possibility for accidents. The latter occurs when drivers attempt to interact with the Smart Santander Application while operating their vehicle distractedly to obtain updated parking space availability information.

6.2.14.3 Design change or opportunity

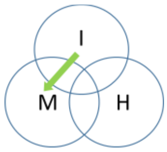
The city nor the service provider have concrete plans to improve the design. There is a future vision to connect the system with an application such as Google Maps or Microsoft Bing that could provide verbal cues to the driver while driving. Through this new Material Agency (system affordance), the map would not only be used to guide the way to the desired destination, but to guide the driver continuously and directly to a free parking space within the vicinity. This design idea is still in its infancy and the realization would be several years in the future, possibly in connection with self-driving cars. This activates changes to the Material Agency circle in the SBF:



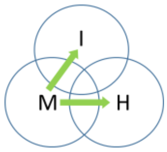
Future possible time instantiations would encompass the design change:



Followed by the accommodation of the altered design in the technology:



Followed by a wide-spread parking system reconfiguration that would drastically affect the acceptance of the solution:

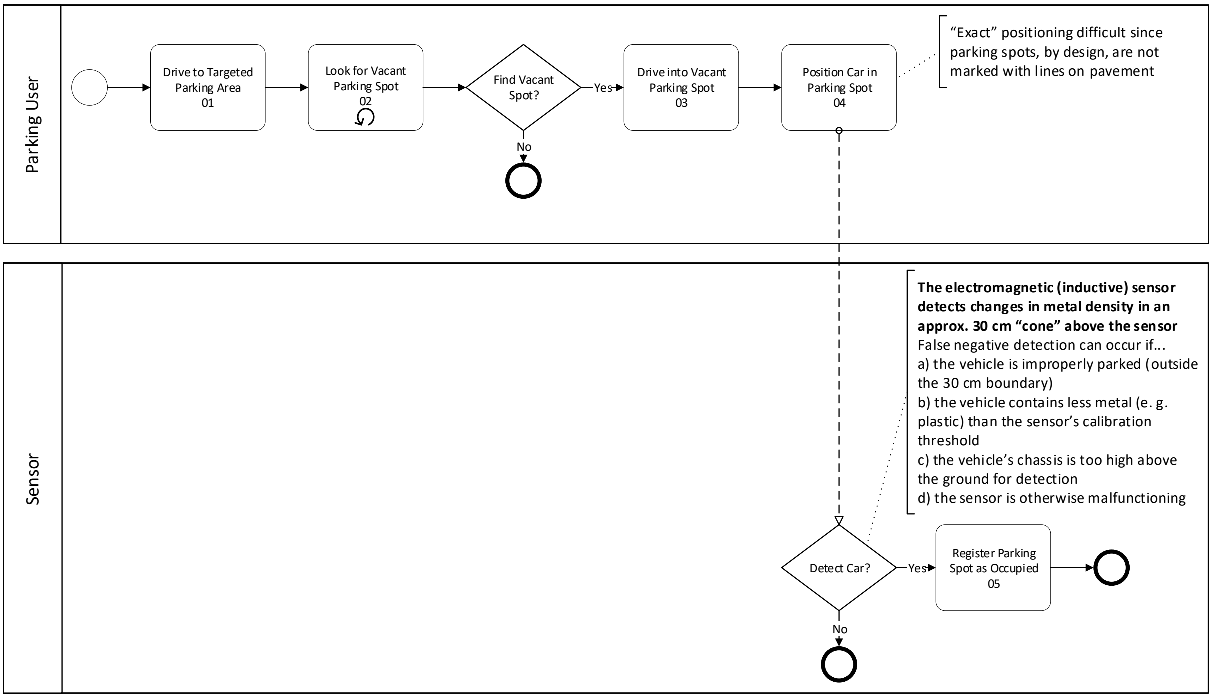


6.2.15 Key finding: Free parking space visible on Smart Santander Application may no longer be available upon arrival – UC: Expected parking space unavailable

6.2.15.1 Design

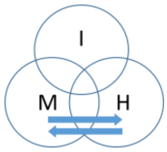
The steps to park a car are depicted in Process 04:

Process 04 — Park Car



After selecting a parking spot from the Smart Santander Application on his/her mobile device, the driver then proceeds to the targeted parking area (Step 01) and looks for the vacant spot (Step 02), which is being repeated until a vacant spot is found as indicated in the diamond-shaped decision symbol. In Step 03, the driver enters the vacant parking spot and positions the car to complete the parking manoeuvre (Step 04). The system records the fact that now a car is parked, at Step 05, and registers the parking spot as 'occupied' in the database that feeds the Smart Santander Application.

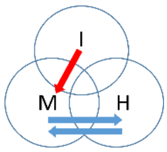
The design of the system that poses a time delay between the identification/selection of a parking space through the application, and 'claiming' the parking space later, also applies to this key finding where the SBF pathways provide availability information to the user (M → H) and the user selects a desired parking spot from the available suggestions (H → M):



6.2.15.2 Realized behaviour and UC

It is a frequent occurrence where a previously available space (marked as ‘free’ in the application) is no longer available upon arrival, causing frustrations with drivers. One user of the system who was interviewed expressed his frustration with “*sometimes the phone is just too slow in displaying the right information*” (Informant R8). While the system works as designed, there are two design limitations that cause the system not to meet expectations: 1) The system’s inability to provide up-to-date information to the driver, post-selection, and pre-arrival at the parking spot. With more real-time communication, the driver would have the option of aborting the plan to park at the currently envisioned parking spot and to select a different spot. 2) The inability to reserve a parking space through the application. If this were possible, then the pre-selected parking spot could be marked as ‘unavailable’ for other drivers and the likelihood would increase that the space is in fact available when the driver arrives at the chosen location.

The negative affordance lies in the design where the missing pathway from I → M does not support the functionality that would otherwise avoid the problem altogether:



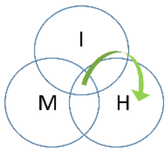
In a normative description, this is being expressed as:

Whenever < driver decides to park car at a pre-selected parking spot
If < parking space is no longer available upon arrival
Then < user
Is < must
To Do < not park at the previously selected parking spot

This has presented a lack of convenience for the drivers (users) in addition to resulting in a subsequent erosion of trust in the system.

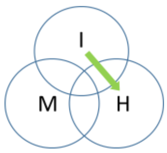
6.2.15.3 Design change or opportunity

The complexity and scope of the technical ramification make a design change challenging where neither the city nor the service provider has the intent to alter the design soon. As a stopgap to counteract the issue of trust, the city of Santander conducted an educational campaign among the users of the application. Here, users were advised to target street parking areas that show more available spaces in the application. This is expected to lead to a higher probability of finding an actual parking space when a driver targets the specific area. The city also contributed to the formation of a new routine to guide drivers to rely more on the street display panels since the time delay between noticing parking space availability information and attempting to park the car is significantly reduced in this scenario. For the purposes of the SBF, the compensating action by the city of conducting the educational campaign attempts to shape new habits:

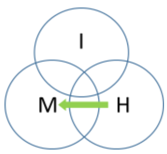


The actions directed at circle H educate the user (driver) base and suggests targeting less frequented parking areas as well as an increased reliance on street display panels.

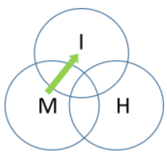
One this direction to the users was given:



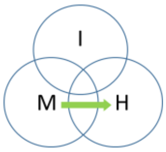
Users altered their parking behaviour and targeted more available parking areas:



Which in turn affected the availability of spaces:



And lastly, a positive change in the user’s perception regarding the accessibility of parking:

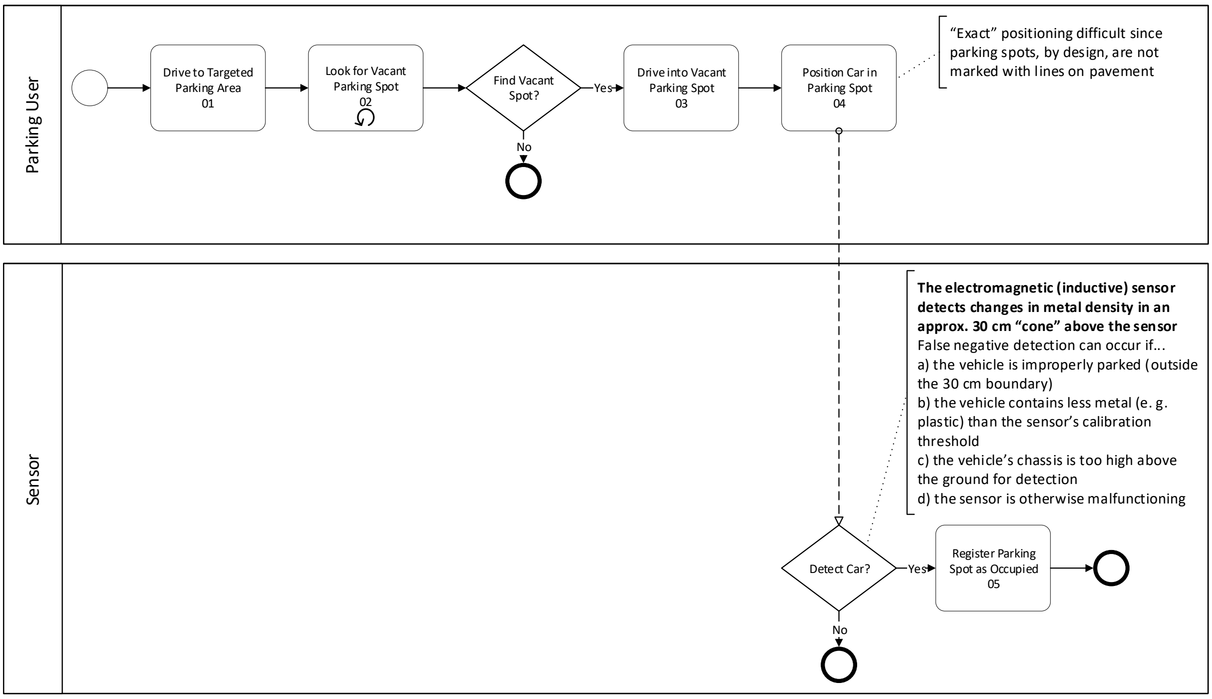


6.2.16 Key finding: Inexact car positioning on sensor – UC: Expected parking space unavailable

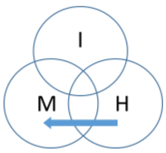
6.2.16.1 Design

This finding, like the one explained in Section 6.2.15, relates to Process 04:

Process 04 — Park Car



Once the driver selects and parks the car (Steps 01-04), the next process stage is for the sensor to detect the parked car, before the parking spot can be registered as 'occupied' in Step 05. The system is designed to confirm that a vehicle is above a parking sensor for the space to be registered as 'occupied'. From an SBF pathway perspective, the user parks the car on top of the sensor (H → M), which allows the sensor to recognize and record its current unavailability for other users:

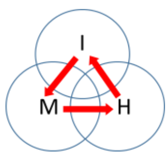


6.2.16.2 Realized behaviour and UC

The parking sensors detect metal density changes in a cone-shaped area extending from the sensor, which identifies if the space above is free or occupied. The sensor registers when a large metal object is placed above it with the detection area having a radius of approximately 30 centimetres, i.e., a diameter of approximately 60 centimetres surrounding the sensor. If drivers who park their car position it outside of the 60-centimeter diametral range, it is a technical limitation that the system does not recognize the parking spot as occupied. In addition, there is a general ± 0.5% error rate for readings that can negatively contribute to this issue and that translates to approximately 5 incorrect readings for every 1,000 cars parked. This UC is rooted in the system design and its associated technical capability.

What greatly exacerbates the problem of inexact car placement and haphazard parking above sensors is the fact that Santander opted not to mark designated street parking spots through painted lines on the pavement. In an analysis conducted jointly by the municipality and the service provider, it was determined that painted lines would reduce the number of available spaces between 10% and 20%. This is due to the simple fact that cars have varying lengths and by keeping their relative parking positions flexible within a row, i.e., one side of the street, it allows for more cars to be parked in this row. As an example, if the row measures 100 meters in length, and parking spots are marked via lines that are five meters apart, it conceivably allows for a maximum of 20 cars to be parked. Since there are smaller cars that do not require a full five-meter parking space, the unoccupied area before and after the car would remain unused. In the 'unmarked scenario', drivers can park cars based on the relative position of the preceding and succeeding vehicle, thus facilitating the 10% to 20% increase in space utilization. The additional capacity has a direct effect on maximizing the service provider's profit. From a purely technical perspective, this choice can be seen as poor design quality, that was accepted for general profit maximization.

The technical inflexibility of the sensor (circle M) that is incongruent with the design (I) also affects the user's behaviour (circle H) in that it is leads to mistrust in the design of the system (circle I):



The system's design expectation is as follows:

Whenever < car is parked in the street

If < metal object is placed above the sensor

Then < system

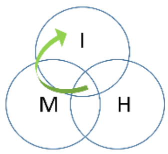
Is < must

To Do < record space as ‘occupied’

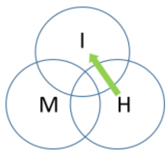
The result of this UC, like with all other problems that could mis-record a parking space status as ‘free’ when it is in fact ‘occupied’, leads to an erosion of trust in the system. It also represents a lack of convenience for drivers since a previously targeted parking space is found to be unavailable upon arrival.

6.2.16.3 Design change or opportunity

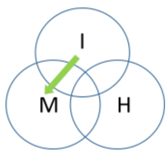
The issue could have been detected through better user testing prior to going live with the solution. The current thinking is to eventually replace the existing sensors with the next generation of technology that promises a wider reading radius as a contributor to increased sensor reading accuracy. Over the years, the city and the service providers have re-evaluated the question whether to change the practice of not having painted parking space delineators. This rule-change would be the single most alleviating factor in dealing with the problem:



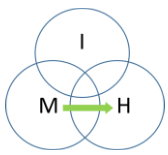
If this were implemented, we could expect – over time – for the circle’s (red) problem areas to become green. The first instantiation would be the decision to change the design:



This is expected to lead to better technological capabilities of the sensor:



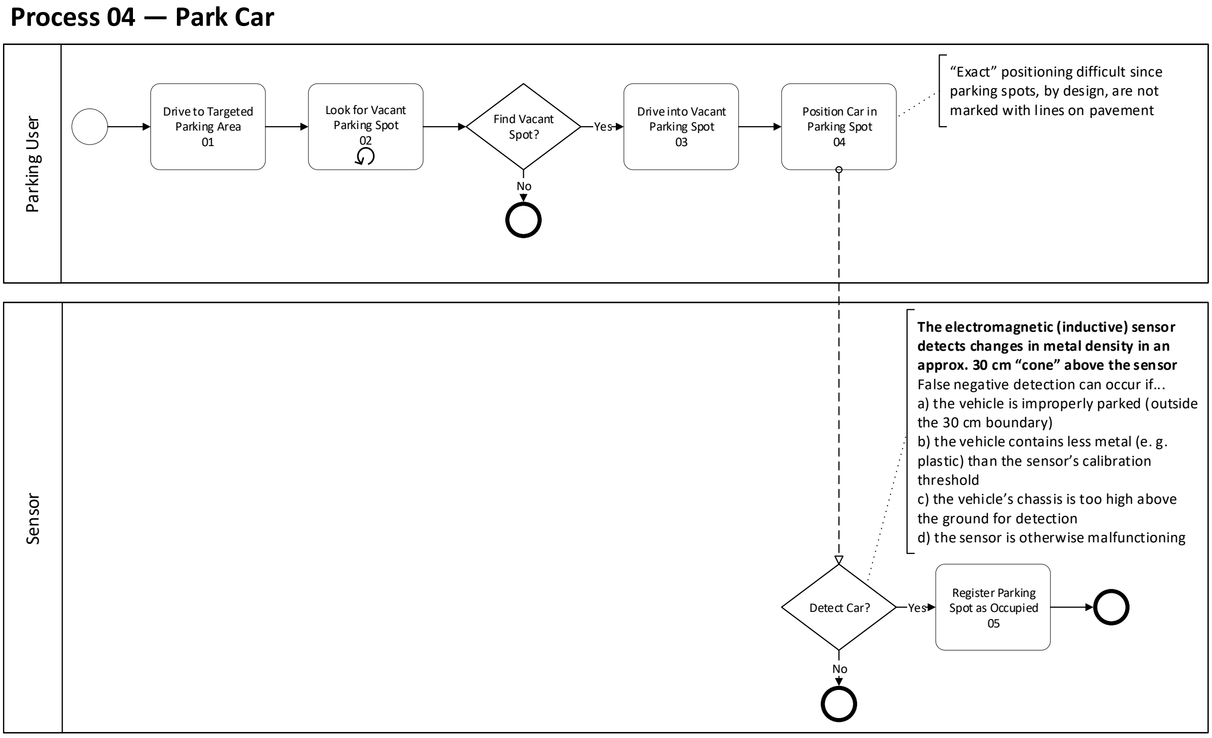
Resulting in a subsequent perception change on behalf of the uses:



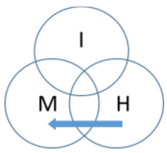
6.2.17 Key finding: Large number of broken sensors that are not being replaced quickly – UC: Expected parking space unavailable

6.2.17.1 Design

The system's credibility depends on the correct and timely detection of parked cars via sensors as described in Process 04:

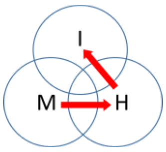


The user selects a parking spot (Steps 01 and 02), enters the spot (Step 03), and parks the car (Step 04). At this point, the system marks the parking spot as 'occupied' (Step 05). The human action of parking the car (circle H) prompts for the sensor (circle M) to pick up the car's metal density:



6.2.17.2 Realized behaviour and UC

The system only fulfils its function when the parked car is registered correctly via the sensor. If the sensor does not work, and a car is parked in the spot, the system does not register it, which leads to an incorrect answer in the availability picture of parking spots and therefore to a trust issue with the user. There seem to be many broken sensors that are not being replaced quickly. Informant R2 commented: *"[the system] does not work very well at all. It's quite often* *that the app says that a space is available, or that many spaces are available, and in the end, another car is parked there or the whole row is full. There are many sensors that are not functioning or not functioning well. The city doesn't replace sensors if they are broken."* Informant R2 specifically refers to the trust issue that emerges from the lack of an accurate parking space picture in the application: *"When [the system] works, then there is no problem, but I have given up looking up parking info. I come and if there is a space, then it's OK."* Another driver, Informant R1 remarked: *"Sometimes, the screen [application] tells you that spaces are available, but when you get to them, they are not available."* The unreliability of the sensor signal (circle M) affects the perception of the user (circle H) whether the system is worth using. Again, leading to a mistrust in the system's design (circle I):



The system's design is as follows:

Whenever < car is parked in the street

If < metal object is placed above the sensor

Then < system

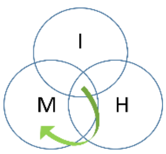
Is < must

To Do < record space as 'occupied'

However, in this case, it is not fulfilled since the 'To Do' line is not followed when the spot is still registered as 'not occupied'.

6.2.17.3 Design change or opportunity

The solution to the problem is obvious in that broken sensors will have to be replaced. It is a correction to the Material Agency within the system:



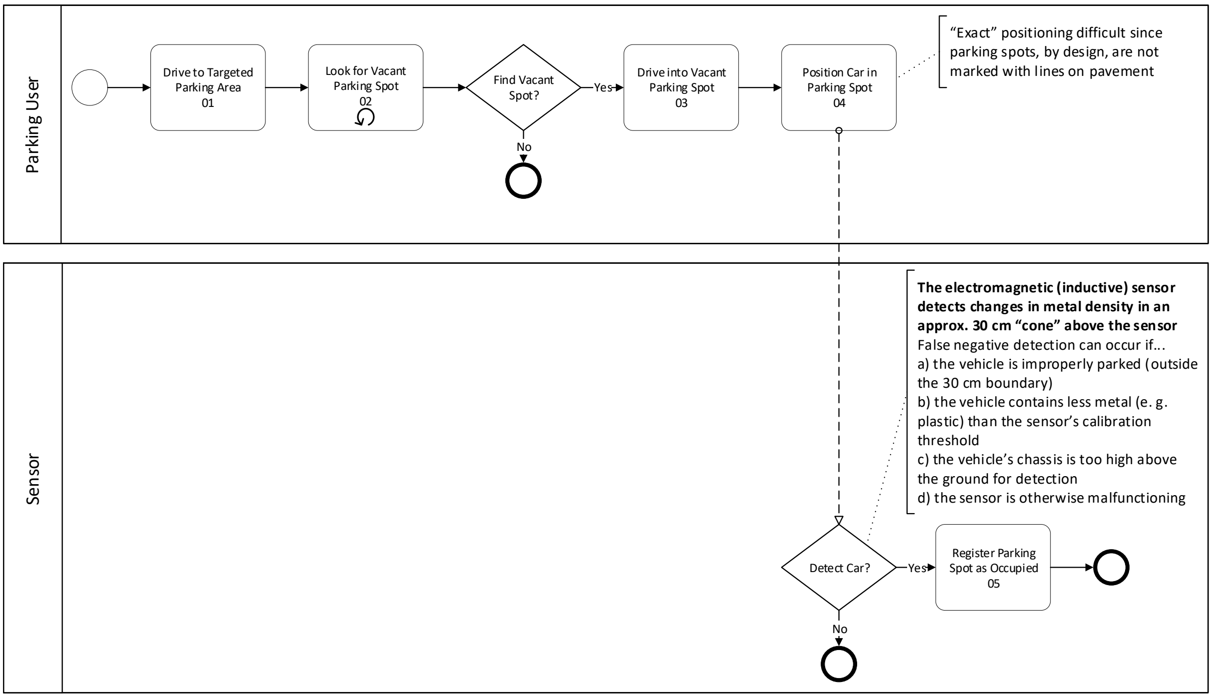
In practice, it is apparent that the solution is often not implemented due to lack of funding, the difficulty in breaking open the asphalt to replace a sensor, and communication issues between city departments when attempting to coordinate road closures.

6.2.18 Key finding: Vandalism of sensors – UC: Expected parking space unavailable

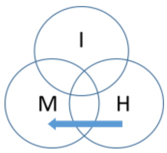
6.2.18.1 Design

Like in previous findings, the proper functioning of parking sensors (Process 04) is a prerequisite:

Process 04 — Park Car



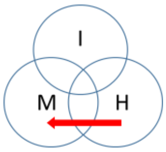
The user selects the spot, parks in it (Steps 01-04), at which point it counts as 'occupied' in the system (Step 05). The human action of parking the car (circle H) prompts for the sensor (circle M) to pick up the car's metal density:



6.2.18.2 Realized behaviour and UC

There have been cases of vandalism where sensors, ordinarily protected beneath the road surface, become exposed. Technical specialists at the University of Cantabria suspect that extreme heat and cold expand and contract the asphalt covering sitting on top of the ground indentation that holds the sensor; thereby uncovering it. This invites deliberate interference with, or destruction of, the equipment. Informant R6 remarked that "*some people break sensors on purpose. Sometimes they don't stay under the street hidden, I don't know, because of the* *rain or something. You can see the sensor in the street and the people pull them out and break them. So, they don't work anymore. Maybe they aren't installed right, otherwise this wouldn't happen. People shouldn't destroy things that are supposed to help us… the city needs to protect them better.*"

In this case, human disposition has a direct influence on the system's functioning:



The parking system user can no longer benefit from the design in practice:

Whenever < car is parked in the street

If < metal object is placed above the sensor

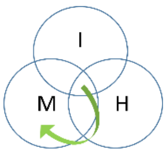
Then < system

Is < must

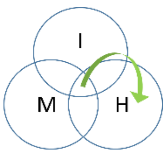
To Do < record space as 'occupied'

6.2.18.3 Design change or opportunity

There are two actions that the City of Santander or Dornier, the parking administrator, could take: First, protect sensors better by proactively looking for exposed equipment or where the quality of the surfacing may lead to exposure soon. The city or Dornier could deal with these (impending) problems by 'touching up' faulty sensor coverage in the street. In this regard, and on a longer-term basis, one could also look at road surfacing materials that provide better protection by being more resistant to temperature fluctuations. This solution relates to Material Agency:



Second, the city could conduct a public awareness campaign that the sensors are city, and by extension, communal property. Once people internalize that they are the owners of a piece of equipment, it would be harder to deliberately damage it:

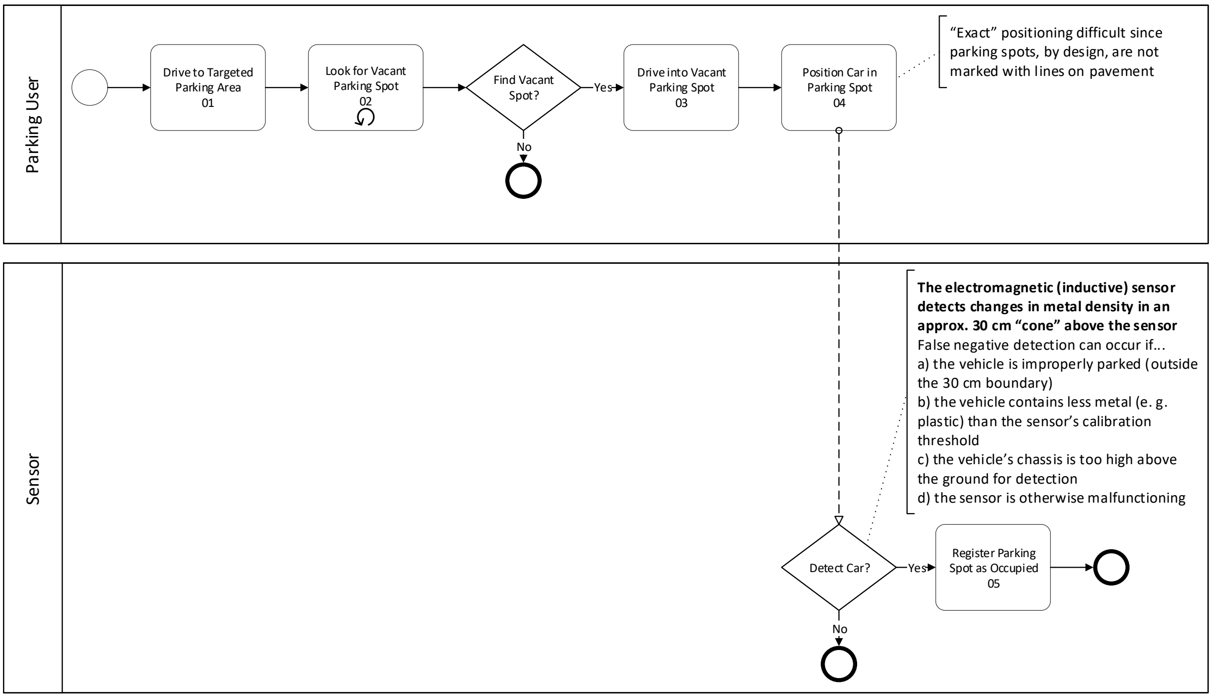


6.2.19 Key finding: Parking solution does not work well for motorcycles – UC: Expected parking space unavailable

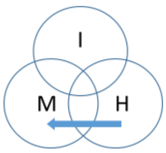
6.2.19.1 Design

As outlined in several previous findings, the proper functioning of parking sensors (Process 04) is a necessity for the system to work:

Process 04 — Park Car



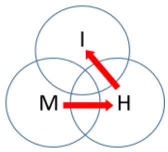
The user's selection of the parking spot and the act of parking the car (Steps 01-04 and circle H) is ultimately expected to result for a space to be properly registered as 'occupied' in the system (Step 05 and circle M):



6.2.19.2 Realized behaviour and UC

Like the finding in Section 6.2.16, the street sensors are not always able to register all objects that are in a parking spot. The two main reasons for missing sensor registration are objects with low metal density or when vehicles are not properly placed above the sensor. The latter is often an issue for motorcycles and conceivably other two-wheeled vehicles that occupy a parking space. If the vehicle takes up the parking space, but is not triggering the sensor signal, the space will show as ‘available’ to other drivers. This contributes to a general trust issue in the system:

The technical limitation by the sensor to pick up the object (circle M) affects the perception of the system (circle H) and causes a general trust issue (circle I):



This was expressed by Informant R9: “*I don’t have a car, but a motor bike and it doesn’t really work well. It’s set up for automobiles, but not for motorbikes. When I park my bike in a spot, it will still be available on the app. I can pay and enter the license plate, etc. But it says that the space is available when it is not.*”

The system’s design expectation remains unfulfilled:

Whenever < car is parked in the street

If < metal object is placed above the sensor

Then < system

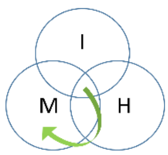
Is < must

To Do < record space as ‘occupied’

The limitation results in trust erosion in the system by showing that the space is available when in fact it is not.

6.2.19.3 Design Change or Opportunity

The most effective solution is to either install sensors that are more technically advanced in detecting a wider range of objects. Alternatively, switching the detection technology to cameras would significantly increase the accuracy, but regulatory limitations with Spain’s data privacy laws have prevented such a solution:

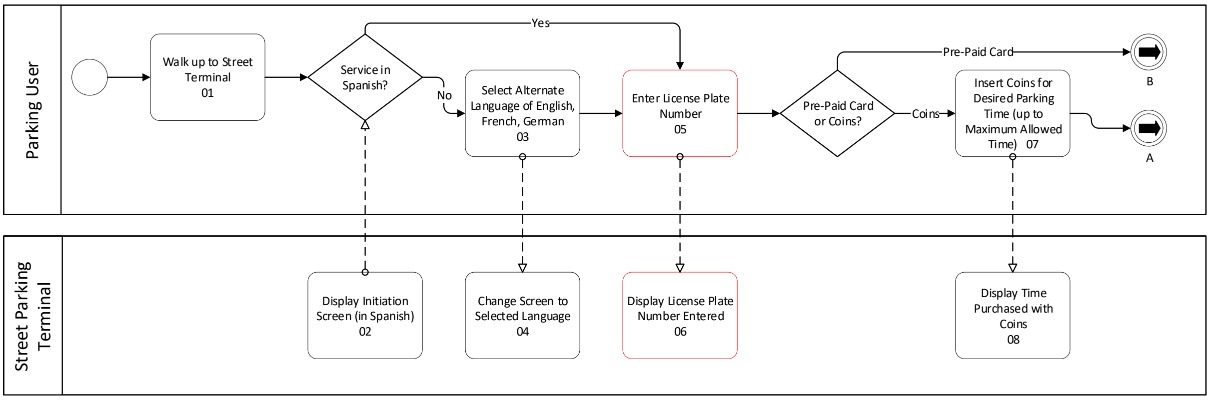


6.2.20 Key finding: Incorrect entry of license plate number at street terminal causes parking violation despite payment – UC: User frustrated by fine

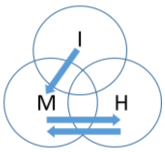
6.2.20.1 Design

The parking user has the choice between paying with the Telpark application, if s/he has registered with the service, or walking up to the street terminal to pay for parking:

Process 08 — Initiate Parking Session with Street Parking Terminal



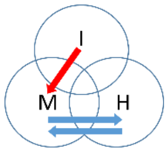
In this case, the user walks up to the street terminal (Step 01), selects the language (Steps 02-04) and then enters the car's license plate number (Steps 05 and 06) before the system proceeds with the subsequent process flow to collect payment. Upon entering the license plate, the system records the information in a database that later serves as a record for all valid parking sessions for the purpose of detecting parking violations. The intended pathways in the SBF are as follows:



The design expects for the terminal to receive the license plate number as expressed in arrow I → M. Arrow M → H prompts the user to enter the license plate while arrow H → M then receives the entry.

6.2.20.2 Realized behaviour and UC

There are cases where the parking user enters the license plate number incorrectly (human error), causing an incongruency with the design of the system:



The missing SBF pathway arrow is I → M since the user's action is not in line with the design's expectation. This has the unintended effect that the scanning vehicle will flag this as an exception since there will be no match in the database with the license plate of a parked car. The formal norm (design) is therefore:

Whenever < scanning vehicle checks for a valid (paid) license plate number
If < license plate number does not match parking database
Then < system
Is < must
To Do < flag a parking violation

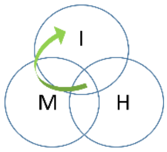
The results are twofold as identified in the interviews:

The parking violation ticket is regarded as erroneous by the recipient since the person has originally paid for parking. This causes primarily citizen frustration since the driver did not expect to receive a fine. The secondary cause of this occurrence is lack of user adoption due to this frustration. The person can contest the violation ticket by submitting the original printed parking ticket, if the person still possesses it, via mail or in person, as proof of the mismatch between the license plate numbers (lack of convenience).

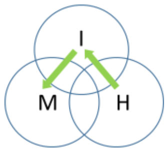
However, there is a positive side effect in that this circumstance has contributed to fairness in the system by automating the verification process. The decision whether to issue a ticket is no longer at the discretion of a parking controller. There has also been an increase in the service provider profit since parking users encountering this problem may simply choose to pay the fine. The latter is often caused by the person no longer having the receipt as written proof that there was a number mismatch – or as an alternative, the person does not want to invest the time to contest the ticket.

6.2.20.3 Design change or opportunity

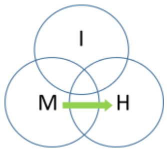
The system was subsequently re-designed to include an additional verification step upon license plate number entry by asking the user to confirm the information that was entered. This was a simple low-cost change to reduce erroneous entries. It took place through the formation of an additional step in the design – as expressed through arrow 9 from the middle leaflet to circle I:



The correction of the problem first occurred through the design change (H → I) that was also carried through to the system's function (I → M):



In the next temporal instantiation, the system's improved functionality (M) lessened user's frustration (H):



The formal norm (design) was modified as follows:

Whenever < system records the license plate number
If < license plate number is being entered by the user
Then < system
Is < must
To Do < display message 'please confirm that license plate number is correct'

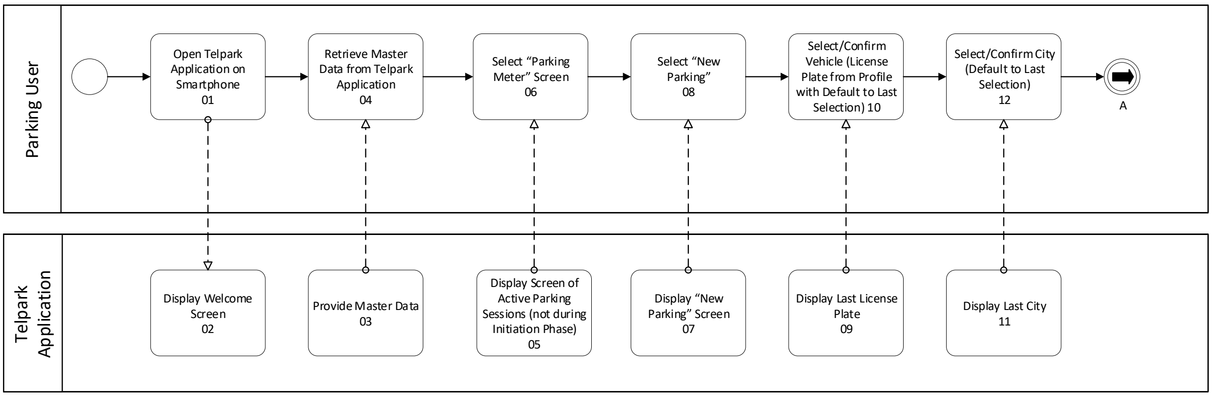
The process could be vastly improved if it did not depend on the user to correctly enter his/her license plate number. The automatic detection of the license plate, for example through installed cameras, is technically feasible, but currently not implementable due to Spain's data privacy laws. There has not been a change to the scanning vehicle process design or any other design element.

6.2.21 Key finding: Incorrect selection of license plate in Telpark application – UC: User frustrated by fine

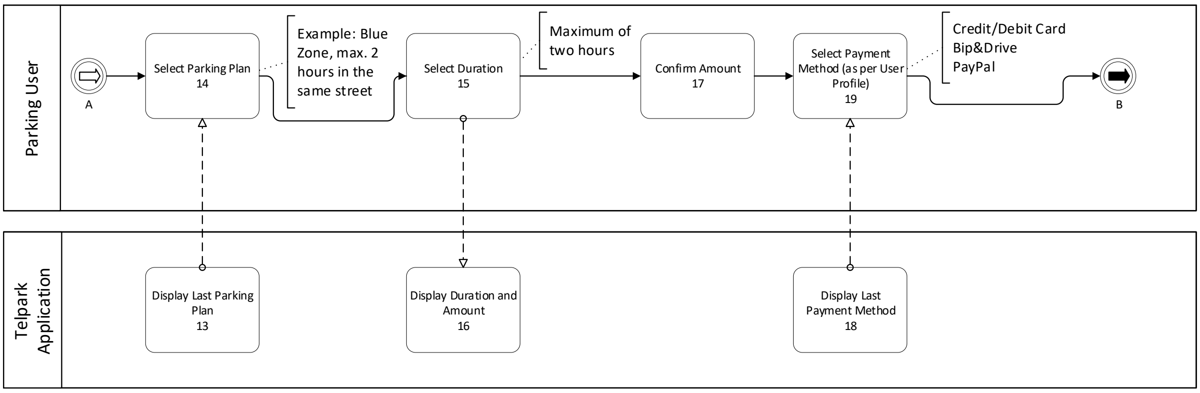
6.2.21.1 Design

The parking user has the choice to conduct the parking transaction via the Telpark application instead of walking up to the street terminal:

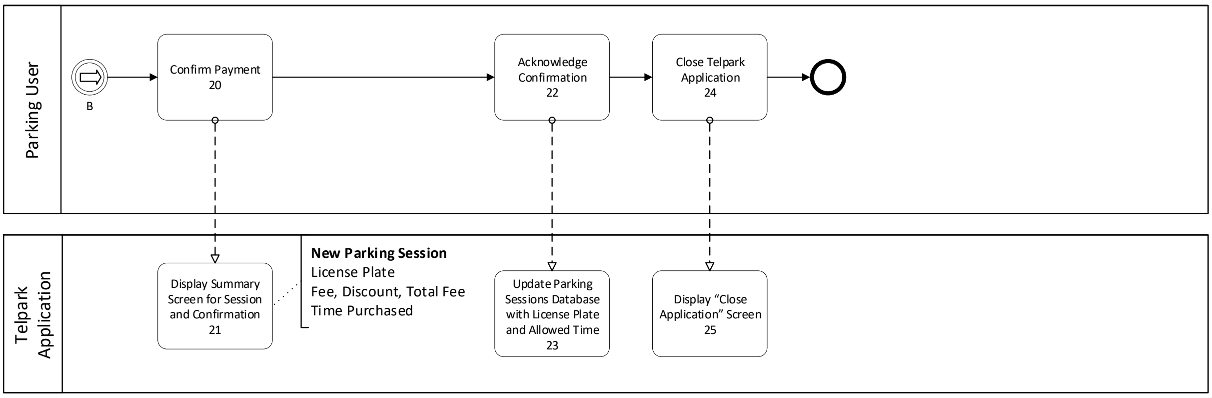
Process 05 — Initiate Parking Session with Telpark Application



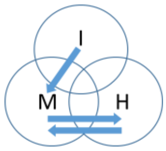
Process 05 — Initiate Parking Session with Telpark Application



Process 05 — Initiate Parking Session with Telpark Application



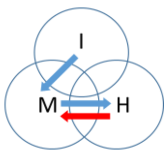
After initializing the application in Steps 01 and 02, the system displays the master data of the user that has previously been captured (Steps 03 and 04). It then allows for the creation of a new parking session (Steps 05 through 08). As a default, the license plate number that was last used is served up on the screen (Step 09) and the user can accept it or select a new license plate from the previously entered master data (Step 10). Similarly, the application suggested the last city that was used (Step 11) and the user accepts or changes it (Step 12). Finally, the system displays the last parking plan that was selected (Step 13) or allows the user to select a new plan (Step 14). After choosing the duration (Step 15), the system summarizes the duration and to-be-charged amount for parking in Step 16. The user confirms the amount in Step 17 and the system subsequently enters the payment routine. This takes place by displaying the last payment method in Step 18, which the user can accept or change to another previously defined payment method in his/her master data record (Step 19). After confirming payment (Step 20), displaying a summary of the transaction (Step 21), the user acknowledging the confirmation (Step 22), the Parking Sessions Database is updated with the registered license plate number and the allowed (i.e., purchased) time to park (Step 23). Lastly, the application is closed in Steps 24 and 25. The intended pathways in the SBF are as follows:



The design expects for the application to receive the correct license plate number that corresponds with the license plate of the car that is actually parked in the parking spot (Step 10). This rule is presented in arrow I → M. Through arrow M → H, the user is prompted to choose either the default license plate number that was last used, and which is served up on the screen in Step 09, or select a new license plate from the previously entered master data via Step 10. The user's choice is expressed through pathway H → M.

6.2.21.2 Realized behaviour and UC

There are cases where a driver has more than one car and therefore more than one license plate in his or her master data record. This opens the opportunity to select a license plate number in the system that does not correspond to the license plate of the car that is parked in the space. For example, if a driver parked 'car A' the last time when using the application, the system will again suggest the license plate of 'car A' as the default for the new transaction. If the person now has parked 'car B', yet accepts the suggested license plate record for 'car A', the two data points will not correspond. Since the currently selected license plate is sent to the Parking Sessions Database in Step 23, it is now the license plate that the scanning vehicle will expect during an inspection run. The user made an error as s/he did not act in conformance with the system's design and creates an issue in the H → M pathway:



The UC that follows is for the scanning vehicle to flag an exception because of the data mismatch between the Parking Sessions Database and the detected license plate of the car that is (in actuality) parked in the spot:

Whenever < scanning vehicle checks for a valid (paid) license plate number

If < license plate number does not match parking database

Then < system

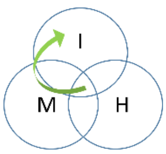
Is < must

To Do < flag a parking violation

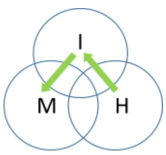
The outcome of this unexpected occurrence is virtually identical to the issue outlined in Section 6.2.20. It causes frustration once the citizen receives the parking violation ticket. The person does not expect a fine since the erroneous choice of the license plate number was made by accident. Most people who encounter this situation will contest the ticket, which results at least in a lack of convenience. The parking operator usually waives the fine in cases where the circumstances suggest that such a problem occurred. The interview data also revealed that the problem mostly occurs with new and inexperienced users and that, after a ticket was received, the person tends to be more conscientious when selecting the license plate record. There are cases where recipients of fines do not contest a ticket, either because they do not pay attention to the mailing, do not respond within 14 days (the maximum allowed contestation period), or simply prefer to pay the fine to avoid the inconvenience. These administrative steps have in the past caused system adoption issues. Also, as a positive UC, there is a slight profit increase on the side of the parking service provider.

6.2.21.3 Design change or opportunity

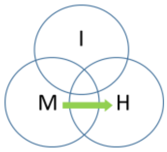
The required confirmation of the selected vehicle license plate in Step 10 directly addresses the problem since it prompts the user to check the information and explicitly confirm the choice. The human error is minimized through a simple system design improvement that involves strengthening the design by a change in the I circle:



In time-phased remediation steps, similar to Section 6.2.20, the correction first occurred through the design change (H → I) that was also carried through to the system's function (I → M):



Then, the system's improved functionality (M) lessened user's frustration (H):



The detailed design steps are now as follows:

Whenever < system records the license plate number

If < license plate number record is selected by the user

Then < system

Is < must

To Do < display message ‘please confirm that license plate number is correct’

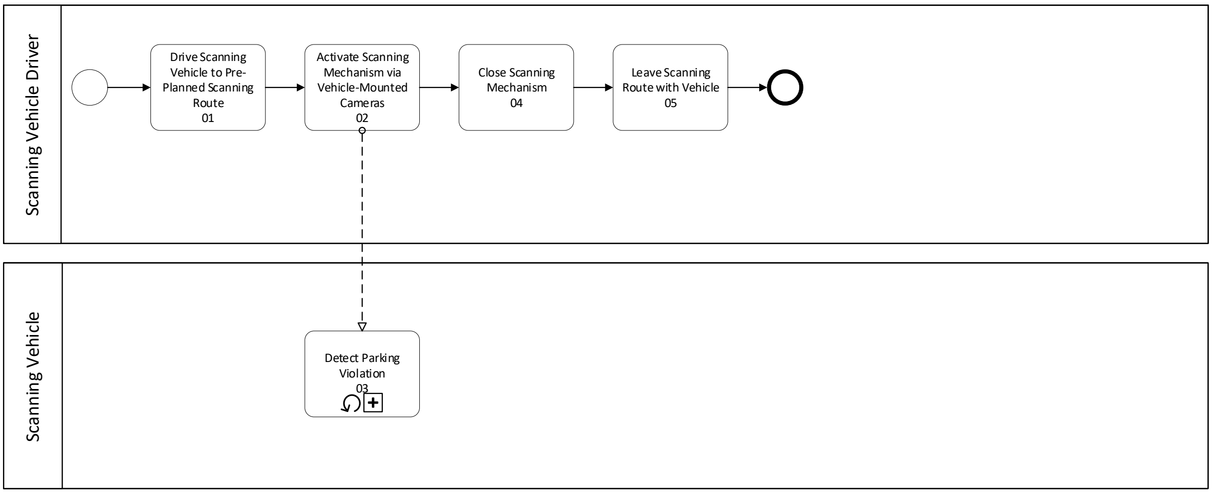
The problem could be entirely avoided if the system were to detect the license plate of the parked car automatically, for example via installed cameras. This is not possible due to Spain’s strict privacy policy on public camera usage. There has not been a change to the scanning vehicle process design or any other design element.

6.2.22 Key finding: Conspicuous scanning vehicles prompt people to outrun them to avoid a fine – UC: User outruns scanning vehicle to avoid fine

6.2.22.1 Design

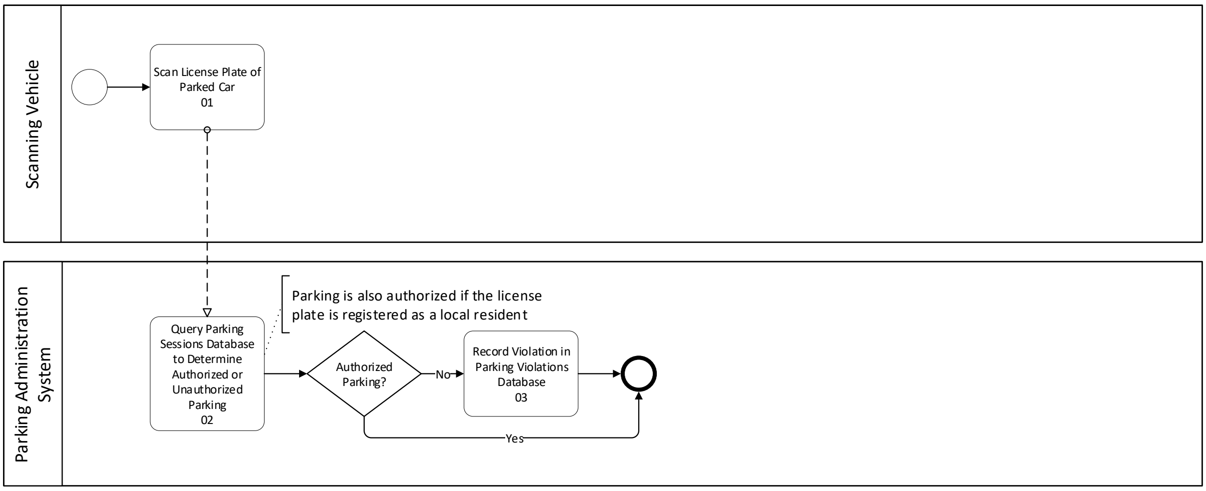
The parking enforcement process in Santander utilizes camera-equipped electrical vehicles that can scan between 2,000 to 2,500 license plates per hour (see Figure 5.5). These vehicles are operated by drivers and used in more than 80% of the patrol routes. Only highly densified streets in the downtown core are served by patrol officers, on foot, to better manoeuvre space constraints. Therefore, for most parking patrol routes, the following process applies:

Process 11 — Scan Parked Cars

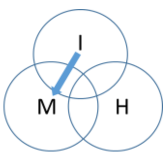


Step 01 positions the vehicle at the start of the area to be scanned whereby the actual scanning occurs in Step 02. Parking violations are then detected by the system (Step 03 – further explained in Process 12 below) and the scanning session is closed out Steps 04 and 05.

Process 12 — Detect Parking Violation



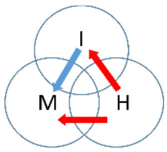
The vehicle scans the license plate of the parked car (Step 01) and queries the Parking Sessions Database to determine if parking for this license plate has been paid for (Step 02). If the license plate is determined as 'not authorized', the system records the violation in the Parking Violations Database (Step 03). This is expressed in the SBF pathway from arrow I → M:



The business process designed by the parking system operator envisions scanning of the license plates of all parked cars along the scanning route. By querying the database, the determination is made whether the car is authorized to park in the parking spot.

6.2.22.2 Realized behaviour and UC

There are instances where users do not pay for parking on purpose. There are also instances where users know, or suspect, that they underpaid for the parking time that they consumed. The sight of an approaching scanning vehicle (Process 11) can cause the owner of a parked car to rapidly attempt to leave the parking spot to avoid a fine: *"people behave differently when they see the inspection [license plate recognition] car. They see the car and then they run to move their own car."* (Informant C2). It is not known to many users that the process of scanning the license plates of parked cars does not automatically translate into a parking violation ticket. Process 13 (proof parking violation) via a dispatched parking controller who takes pictures of the offending vehicle is a prerequisite before a fine can be issued. In this sense, the approaching scanning vehicle alone will not result in any negative consequences for the vehicle operator. Nevertheless, this limited affordance is generally not known and some drivers returning to their parked cars have taken undue risks in the face of an approaching scanning vehicle:



The drivers running back to their cars have developed a human agency workaround and thereby created a new personal norm (habit) that has over time spread to more drivers (pathway H → I). The behaviour causes a potential interference with the function of the scanning vehicle (pathway H → M) and has led to the increased probability of accidents that may involve other motorists, pedestrians, or results in injury to the returning driver by colliding with the scanning vehicle, tripping on the sidewalk, etc.:

Whenever < scanning vehicle is visible

If < driver has not paid for parking and decides to reposition the car prior to scanning vehicle approaching

Then < driver

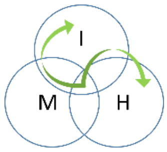
Is < must

To Do < get to car as quickly as possible and leave before scanning vehicle takes a picture of the license plate number

This is therefore a UC resulting from the user's behaviour in response to the designed process.

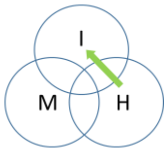
6.2.22.3 Design change or opportunity

The city and the parking solution operator undertook an educational program to sensitize citizens as to the danger of this behaviour. The company placed messages on its interactive mobile phone app and included a leaflet in one of their postal mailing campaigns. The parking solution operator trained their scanning vehicle drivers to be careful when operating the vehicle and to watch for pedestrians who may engage in unexpected and unsafe behaviour. The company also worked with the local police department to collaborate with scanning vehicle drivers to report unsafe pedestrian behaviour to them:

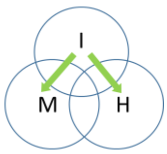


This first influenced a new norm (circle I) for pedestrians, scanning vehicle drivers, and police. Subsequently, it resulted in people adopting this rule (circle H) above. The detailed and time-phased pathways are laid out as follows:

First, the creation of the educational program (I):



This was followed by educating users, training scanning vehicle drivers, and placing messages on the app and distributing them via leaflets (M):

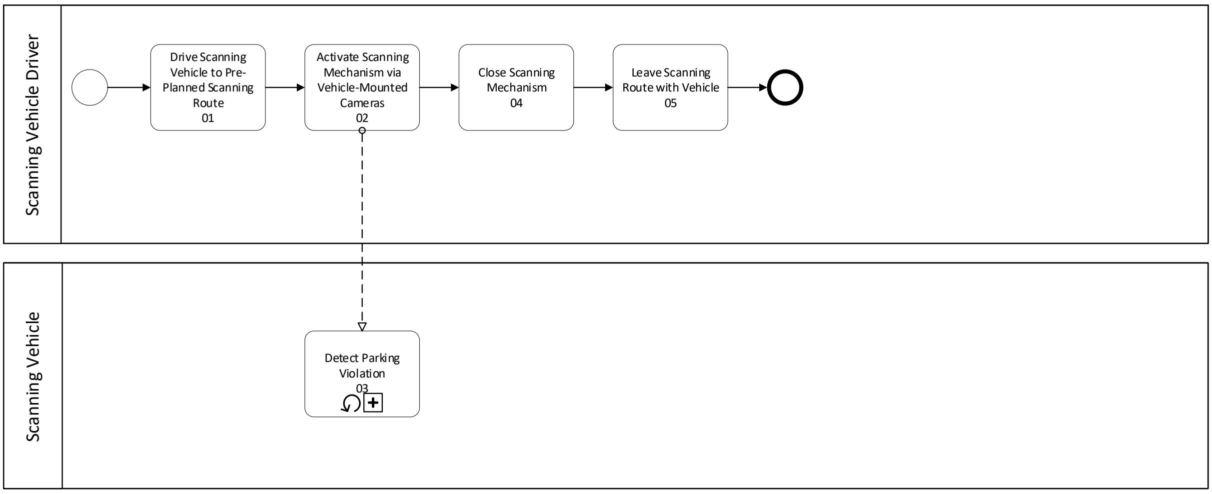


6.2.23 Key finding: Short-term parking with associated vehicle turnover not conducive to efficient license plate reading by camera-equipped vehicles – UC: Drop in scanning vehicle efficiency

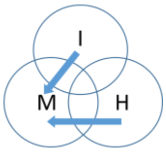
6.2.23.1 Design

The processes for license plate reading through camera-equipped vehicles are described in Process 11:

Process 11 — Scan Parked Cars



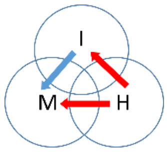
Initially, Step 01 positions the vehicle at the start of the area to be scanned whereby the actual scanning occurs in Step 02. Parking violations are then detected by the system (Step 03) and the scanning session is closed out in Steps 04 and 05. The system is designed to perform these steps most efficiently while continuously operating. The I → M pathway and the (human) scanning vehicle driver operates the device as intended as expressed through the H → M line:



6.2.23.2 Realized behaviour and UC

At the time of setting up Smart Parking in Santander, it was a prime objective by the city and the University of Cantabria to replace human enforcers of parking rules, who patrolled the streets on foot, with automated scanning vehicles. The efficiencies gained seemed obvious and indisputable: human enforcers can read a maximum of 250 to 300 license plates per hour and camera-equipped vehicles increase the throughput to 2,000 to 2,500 license plates per hour. At the start of operating the new system, the parking solution provider dismissed human enforcers and converted all routes to be served by automated scanning vehicles.

After approximately six months of operation, the data showed significant differences in throughput for automated scanning vehicles. On some streets, the hourly throughput of camera-equipped scanning vehicles dropped to a level that was below the previous average throughput of human enforcers. Individual observations of scanning vehicles established a strong inverse correlation between vehicle movement within a street and throughput of license plate readings. As traffic within a street increases, so does demand for parking, which translates into more frequent vehicle slowdowns, stops, reverse driving into a parking spot, leaving a parking spot, etc. The street becomes busier, and the driving manoeuvres impede traffic in general, thereby negatively affecting speed, mobility, and efficiency of scanning vehicles. The Human Agency (the individual behaviour of drivers) in this case negatively influences the performance of the scanning vehicle (Material Agency) and also causes a general trust erosion (Interpretive Schema):



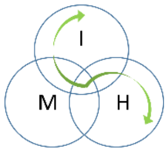
The original design for the scanning vehicle efficiency can be expressed as follows:

Whenever < scanning vehicle moves forward in the street
If < there is an obstruction in front (such as a car)
Then < scanning vehicle
Is < must
To Do < stop and wait

The substandard 'license plate reading efficiency rate' in high traffic areas came as a surprise to the city and resulted in two major negative consequences: 1) Citizen frustration – within busy streets where drivers look for parking spaces. Here, when parallel parking under time pressure, scanning vehicles are seen as a nuisance. This is especially the case when other vehicles are approaching, leaving parking spaces while there is a gap in the traffic, etc. 2) System efficiency – the parking solution provider had counted on the much higher efficiency of scanning vehicles as compared to human enforcers. For high throughput streets, which comprise approximately 30% of the entire downtown parking area, the scanning vehicles proved to be inappropriate and negatively affected the parking solution provider's business case since scanning vehicle drivers took longer to complete tours and had to be paid overtime.

6.2.23.3 Design change or opportunity

For high throughput streets, the city and parking solution provider discontinued the use of scanning vehicles and reinstated human enforcers that patrol these streets on foot. Since the enforcers walk from car to car on the sidewalk, they are not contributing to street congestion and generally proceed faster than scanning vehicles whose forward path experiences multiple traffic obstructions. The limitation in the material affordance of scanning vehicles, namely that they are physically limited (constrained) in their movements through traffic, is compensated by humans who are nimbler and can manoeuvre more easily around obstructions. For medium to low throughput streets, the scanning vehicles remain in place since in this case they are more efficient than humans. The city and parking solution provider have continuously harmonized which routes are covered by scanning vehicles and which ones are served by human enforcers. This led to a new rule (Interpretive Schema) where busy streets are patrolled by human agents (H) and less busy streets are served by camera-equipped scanning vehicles:

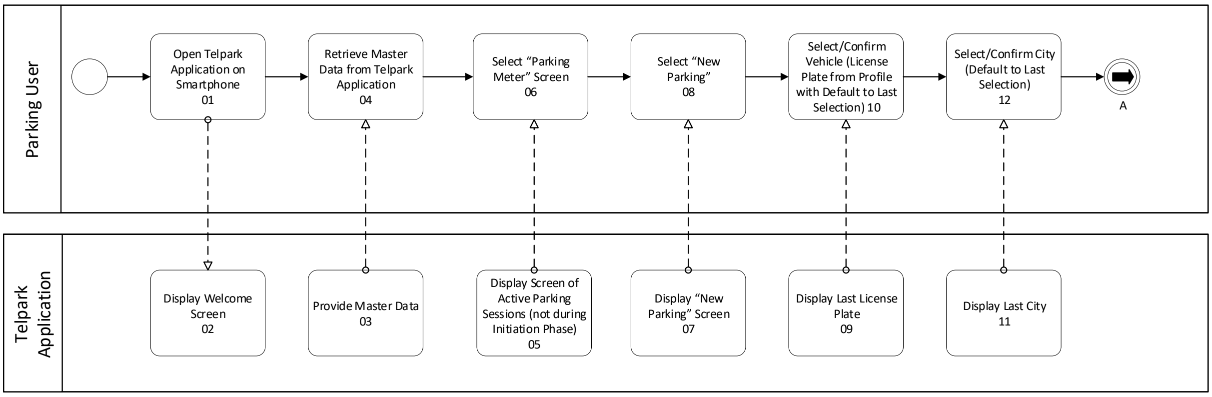


6.2.24 Key finding: Two-hour maximum parking time disrupts and alters social activities – UC: Two-hour parking maximum alters behaviour

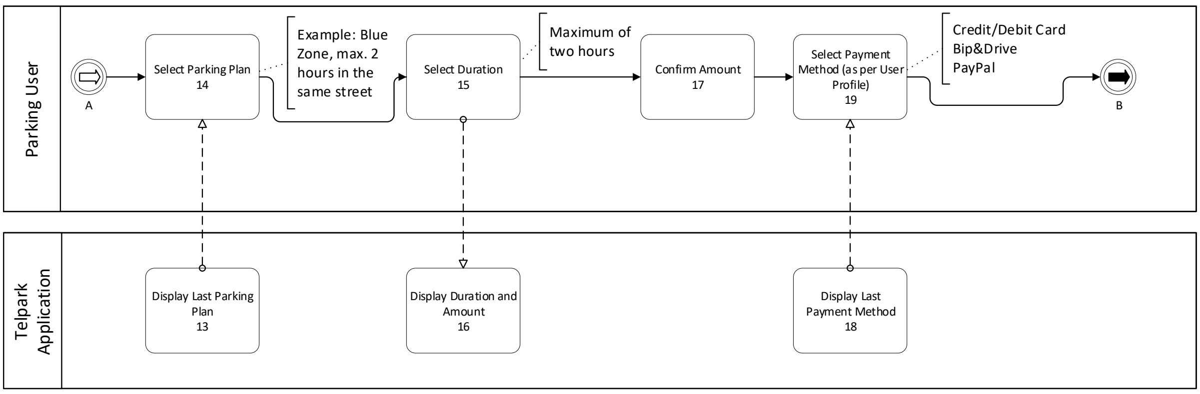
6.2.24.1 Design

The user has the choice of creating a parking session, and paying for it, through the Telpark Application (Process 05) or through the street parking terminal (Process 08):

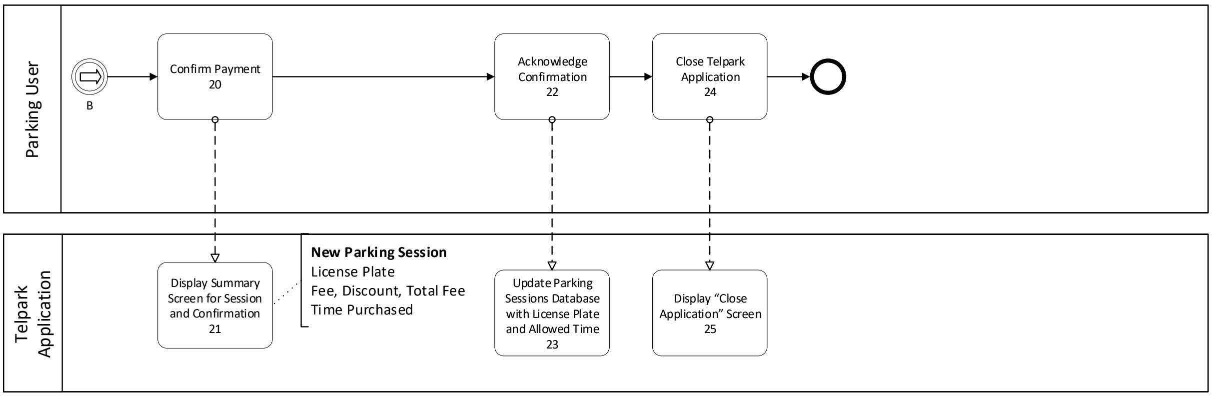
Process 05 — Initiate Parking Session with Telpark Application



Process 05 — Initiate Parking Session with Telpark Application



Process 05 — Initiate Parking Session with Telpark Application

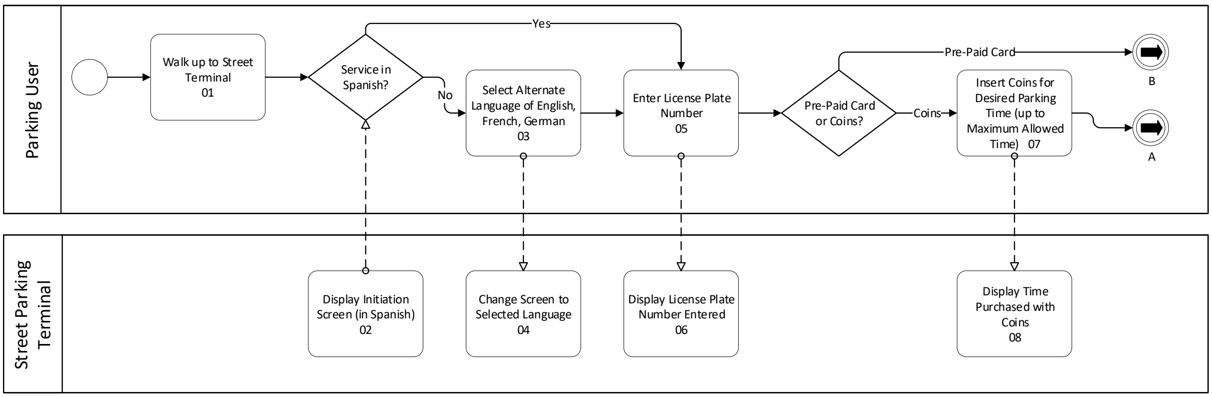


After all initialization and selection steps are completed (01 through 14), the system prompts the user to enter the parking time in Step 15. The maximum parking duration is limited to 120 minutes (two hours) during peak parking times. These are on weekdays from 10am to 2pm and from 4pm to 8pm. The paid parking time on Saturdays is from 10am to 2pm.

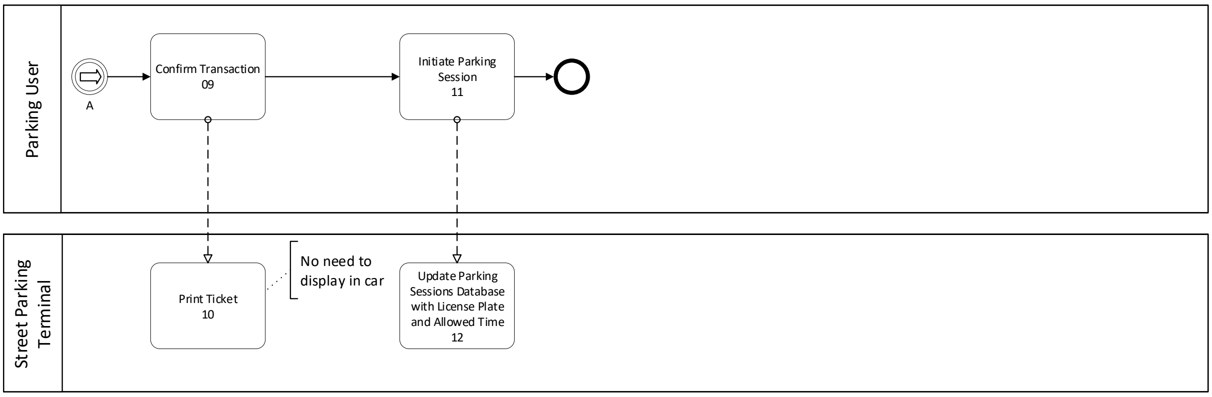
The subsequent process steps handle the required payment and the creation of the parking session in the database (up to Step 25).

If the user opts to pay via the street parking terminal (Process 08), the selection of the parking duration and the application of the 120-minute limit takes place in Step 07, if the person pays with coins, and in Step 15 if the person pays with a credit card:

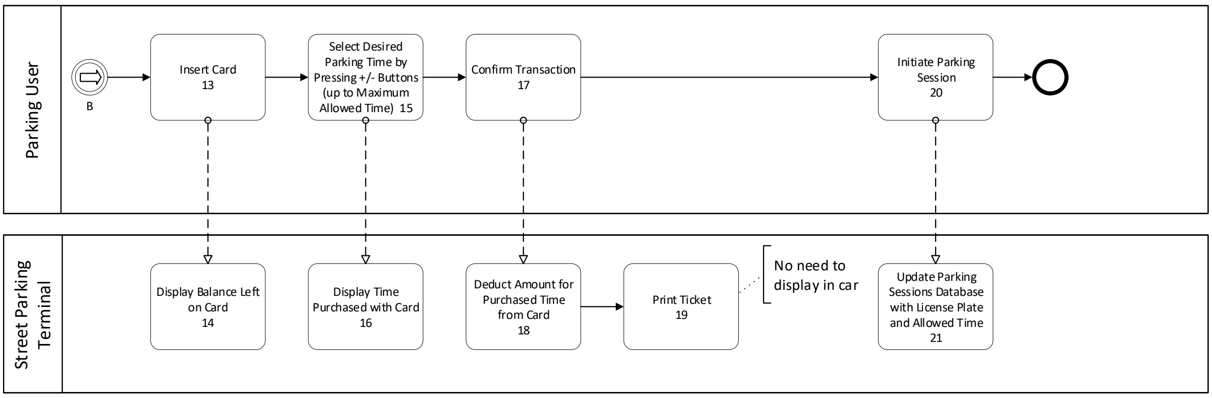
Process 08 — Initiate Parking Session with Street Parking Terminal



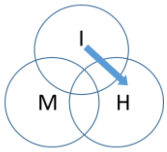
Process 08 — Initiate Parking Session with Street Parking Terminal



Process 08 — Initiate Parking Session with Street Parking Terminal



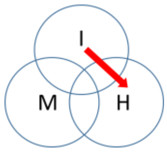
In either case, the user (circle H) is limited to a maximum parking time of two hours through the enablement of this rule (circle I):



6.2.24.2 Realized behaviour and UC

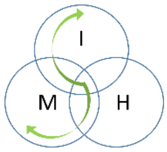
The enforced two-hour limit during peak parking times causes a disruption in the routine of users if they desire to stay for a longer period. Informant R11, an employee at a restaurant in a busy street that is enabled for automated parking, remarked: "*The biggest problem is that during the busy times [peak times] people need to change the space after a couple of hours. If you're having drinks or a bite with us, that is not sufficient time. Maybe it works in the daytime when you go shopping, but it doesn't work in the afternoon or evening. This is a big problem when people spend time with their work, friends, and family. The parking times should be longer so that you don't have to change the car to a different parking.*"

As Informant R11 highlighted, the solution to the problem often lies in people moving their car to a different parking spot. This is time consuming and cumbersome – particularly since the system keeps track of the license plate number and the last parking location. The design is as such where it does not allow the driver to park in a different spot in the same street. The car must be parked in a different street, which adds additional time to the re-parking process. This rule (circle I) poses a disruption to the driver's leisure time in the restaurant. The change to the driver's disposition and personal routine is expressed in circle H:

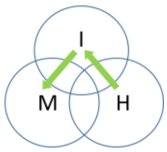


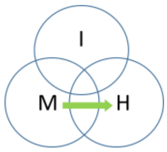
6.2.24.3 Design change or opportunity

The 'two-hour limit' rule has been enacted to enable more drivers to be able to park their cars. Without this rule, a person could conceivably park his or her car for the entire day, thereby rendering the space unavailable for any other driver. However, the rule only makes sense if there is a shortage of parking spaces in the area. If there is not, then a car that is parked for more than two hours would not prevent another driver from parking his/her car. The solution is for the 'two-hour limit' rule, expressed through circle I, to be activated dynamically based on traffic volume (circle M). This would balance the enablement of more residents and visitors to park their cars with the convenience for drivers to overstay two hours if so desired:



In the time phased view, we would again account for the design change (I) that is subsequently reflected in the system (M) and that later is expected to change the user's disposition:



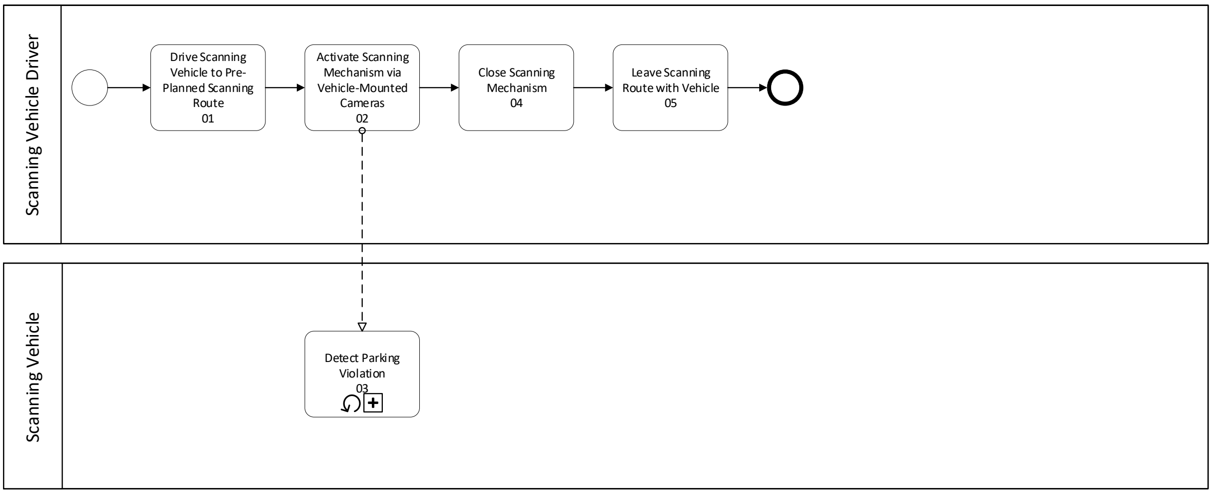


6.2.25 Key finding: Automated parking compliance validation contributes to breaking of rules – UC: Delayed compliance checks conducive to rule breaking

6.2.25.1 Design

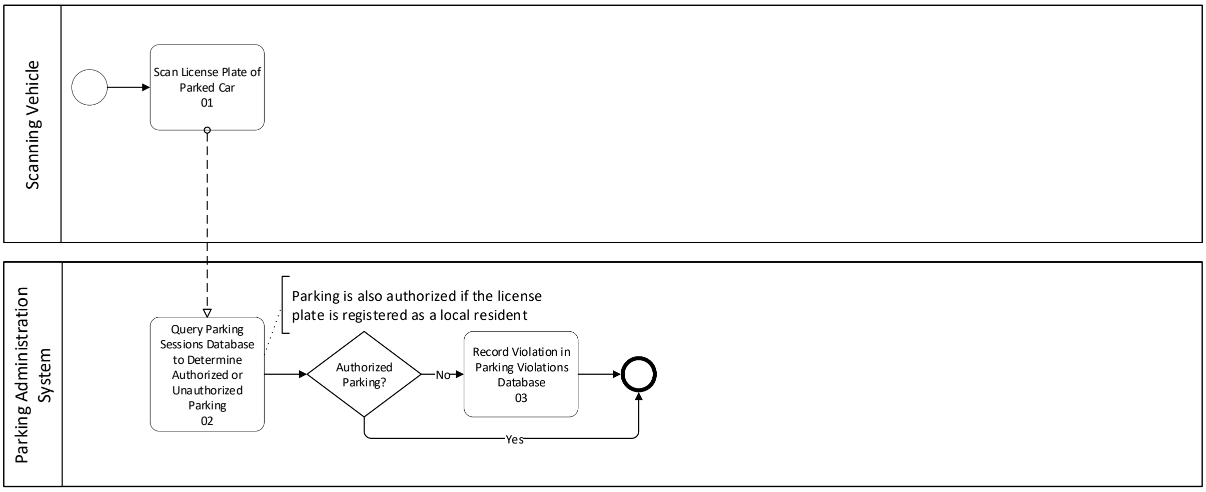
The City of Santander, together with the University of Cantabria, opted for camera-equipped electrical vehicles. These are operated by drivers and able to scan between 2,000 to 2,500 license plates per hour. Approximately 80% of patrol routes are serviced by these vehicles and only highly densified areas (the remaining 20%) are patrolled by officers. Process 11 therefore applies to most patrol routes:

Process 11 — Scan Parked Cars

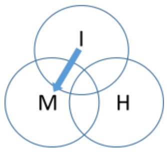


After positioning the vehicle at the start of the scanning area (Step 01), scanning takes place (Step 02). Process 12 handles the detection of parking violations. At the end, Process 11 completes by closing out the session in Steps 04 and 05.

Process 12 — Detect Parking Violation



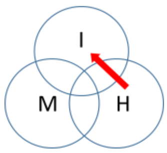
The system scans the license plate in Step 01 and queries the Parking Sessions Database to determine if parking for this license plate has been paid for (Step 02). If the license plate is determined as 'not authorized', the system records the violation in the Parking Violations Database (Step 03). The design (circle I) is comprised of largely automated processes that are executed within circle M:



6.2.25.2 Realized behaviour and UC

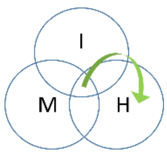
The high degree of process automation, and with this, the absence of uniformed patrol officers, has contributed to users breaking the rules. This predominately takes place by parking without paying or by overstaying the purchased time limit. Informant R15, a policy officer, summarized the problem: "*I see a lot of people that don't pay for parking. It's not my area, but I just notice that. My coworkers here say the same thing. There is no person [parking enforcer] who walks up and down the street all the time. In the past, such a person makes people pay. You never know when he is coming on the street again, so even if he's not here right now, you pay. Now, with the automated machines, you can get away with not paying.*"

This is exacerbated when scanning vehicles only infrequently patrol an area. The design of the system (circle I) is thus incongruent with human behaviour (circle H):

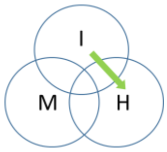


6.2.25.3 Design change or opportunity

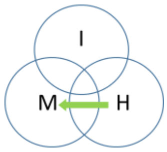
Conceivably, the city could position more human enforcers to counteract this trend, but this solution is not cost effective. The city and service operator have in the past conducted educational campaigns that appeal to a sense of fairness among citizens. This is also reinforced in the Santander Smart City demonstration centre where messaging underlines that not paying for services is akin to 'stealing from the public'. Both change initiatives attempt to influence human agency through people's disposition and personal routines (circle H):



In time-phasing the scenario, the human behaviour change would come first (H):



This is followed by using the system, including paying for it, as it was originally designed:

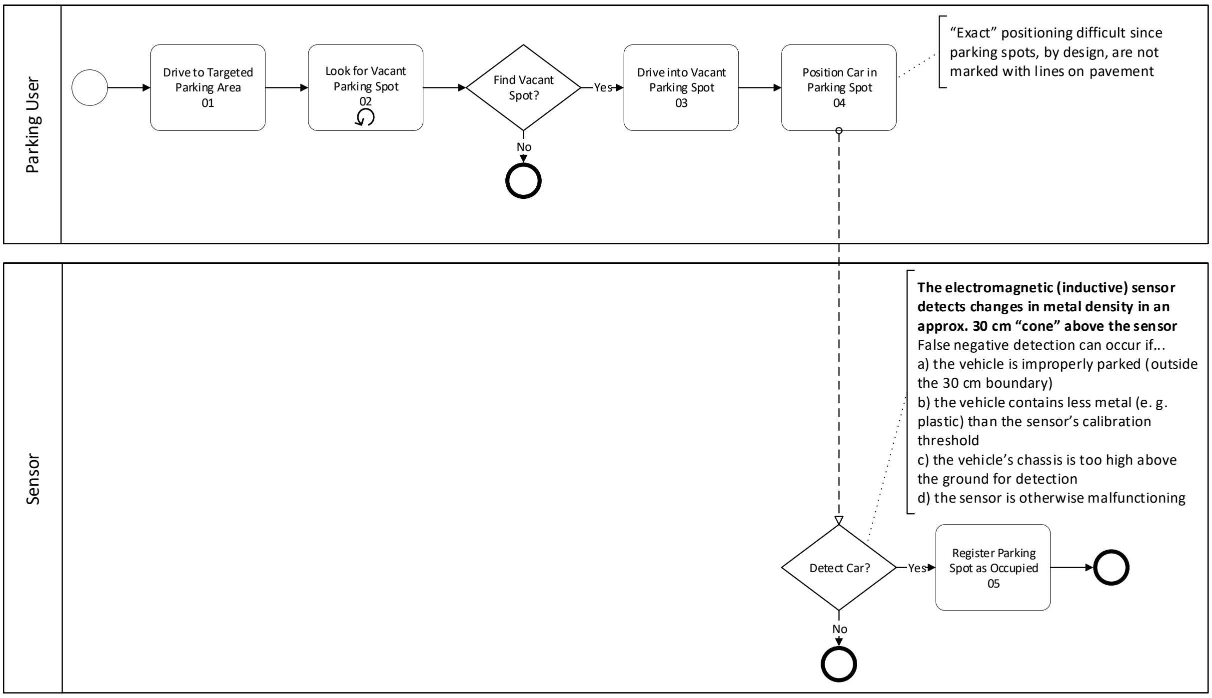


6.2.26 Key finding: Faulty sensor signal – UC: Sensor quality failure

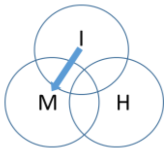
6.2.26.1 Design

This finding is related to Process 04:

Process 04 — Park Car



After selecting and parking the car (Steps 01-04), the system's design foresees the detection of the occupancy status of the parking space (Step 05) with an SBF pathway of I → M:



6.2.26.2 Realized behaviour and UC

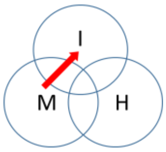
Two key issues influence sensor behaviour that are closely related: the technological capability of the sensor and varying metal density in cars.

The first, technological capability of the sensor, has greatly improved over time. Santander embarked on the Smart Parking initiative in 2010 with the first generation of sensors. The project was spearheaded by the University of Cantabria and, initially, approximately 85 devices were distributed. The university expected for the technology to be more mature and was surprised by how sensors behaved in practice: *"We had to face reality – the technology was far, far, from being mature. The vendors [for sensors] claimed that they had solutions, but they were clearly substandard. The detection was not performing as expected. In the marketing material of the first company, everything was working perfectly – they 'sent the sensors to the moon and back'. The company was very small, but life is much more complex than in a brochure, and the technology only worked in the lab such as when you play with Legos."* (Informants C1 and C2).

The main issue was that the technology operated on a two-axis basis that did not take the depth dimension into account. Since the chassis of a car is not directly touching the asphalt, the ability for a sensor to detect metal 30 to 50 centimetres above the ground (depending on the height of the tires) is a key requirement. The technological advancement to add the third (depth) axis to the sensors occurred in 2011 and the city deployed these improved devices in 2012, which greatly enhanced the accuracy of detection.

The second phenomena that influenced detection is ongoing changes to metal density in cars. Over the years, motor vehicles have been equipped with more plastic parts and fewer components made from metal. This affects the assumptions for programming the detection threshold of the sensor. Even within the same model of a car, the sensor may pick up the signal from a car that is 20 years old, due to its increased metal content, yet miss the same model of a car that is only two years old. The problem required careful calibration by taking different metal and plastic composition rates into account so that the overall detection rate can be maximized.

Both phenomena represent an affordance failure of the sensor scanning architecture und corresponding software assumptions. It is a device quality failure that arguably should have been addressed in user testing prior to implementation as it led to an unexpected impairment of user benefits. The incongruency between the design requirement to correctly sense the presence of a car and the shortcomings of the material capability of the sensor is reflected in a substandard M → I relationship where the material is not doing what is expected of it:



The system's design expectation is as follows:

Whenever < car is parked in the street

If < metal object is placed above the sensor

Then < system

Is < must

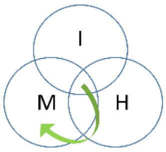
To Do < record space as 'occupied'

Again, the unintended consequence is trust erosion and lack of convenience if the measurement produced by a sensor does not correspond to what takes place in actuality.

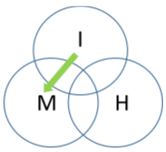
6.2.26.3 Design change or opportunity

The main remedy of the issue has not been rooted in changing the design, but in improving the technology. After the first-generation sensors from 2010 were replaced, the second-generation sensors that were installed in the 2011 to 2012 timeframe vastly improved results.

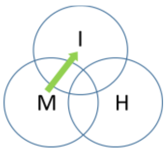
These second-generation sensors also have more sensitive calibration capabilities that allow for better tuning possibilities when it comes to metal density of cars. The technical upgrade of the sensor capability affects Material Agency:



In the time-sequenced view, the design improvement (I) was incorporated in the technology (M):



The additional material capabilities (M) further influenced the future design (I) of sensors:

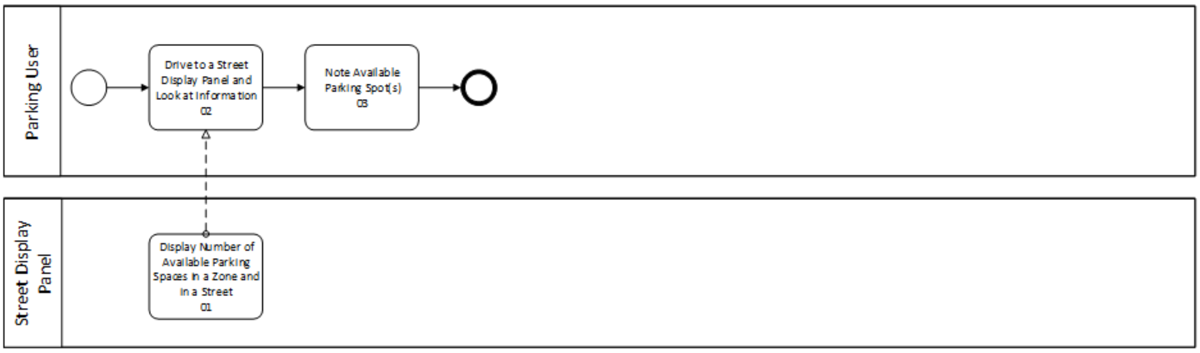


6.2.27 Key finding: Frequent power outages in first generation of street parking display panels – UC: Panel quality failure

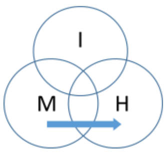
6.2.27.1 Design

The issue concerns the ability for drivers to gather information about parking space availability by looking at the installed display panels on major thoroughfares. The street panels are pictured in Figure 5.8 and described in Section 5.4.3. The steps that drivers undertake to glance at parking availability while driving is outlined in Process 03:

Process 03 — Pre-Select Parking Spot with Street Display Panel

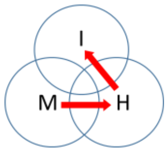


The city maintains several street display panels that show the available number of parking spaces in nearby parking zones and streets (Step 01). This enables the driver to quickly determine, while driving, where it would be most likely to find an available parking space and to direct the car to the street (Steps 02 and 03). The functionality of the system (M) thus enables the driver (H) to modify his or her behaviour:



6.2.27.2 Realized behaviour and UC

The first generation of street display panels exhibited a technical problem in that the power supply unit, through the security breaker, would switch off suddenly and without apparent cause. The exact nature of the power issue could never be determined – it was likely related to moisture build-up within the panel unit itself and for the security breaker to shut off the power supply. Once this happened, the power breaker had to be reset by a technician who had to drive to the affected street panel and manually access the breaker box that is located inside the base of the street panel post. There was typically a multi-hour turnaround time for this to take place. The occurrence is a malfunctioning of the system (M) that prevented the user (H) to gain information, causing in turn for the system to not be trusted (I):



The system's design outlined below was not fulfilled:

Whenever < user looks at the street display panel

If < desired street shows sufficient available parking spaces

Then < user

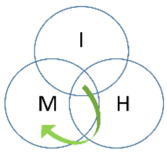
Is < has the option to

To Do < direct car to the envisioned parking zone and street

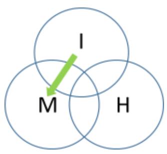
Even though this represented a simple system malfunction that was ultimately remedied by installing the next generation of street display panels, it caused trust issues within the community at the crucial time of implementation. The city had widely advertised the new system with its instant view into parking space availability, but then the panels malfunctioned. This caused trust issues with users, a general disappointment in the solution, and frustration on the part of the system operators: *"We assumed that the technology was a little bit more mature than it was claimed. That was a surprise for us. We then faced the reality. The reality was that the technology was far, far, from being mature. The companies that were claiming that they had solutions, we discovered that they did not."* (Informant U1).

6.2.27.3 Design change or opportunity

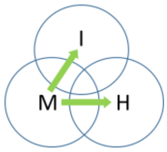
The solution to the problem was the upgrade to the new generation of street display panels (Material Agency), which took place approximately 18 months after the installation of the first generation. The issue has since not recurred and there is a – generally – uninterrupted information flow from the system:



Here, the material problem (M) was rectified:



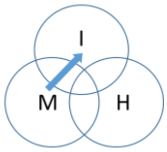
Which subsequently improved the individual's attitude in the system (H) and more general acceptance (I):



6.2.28 Key finding: Sensor damage due to uncoordinated street work – UC: Accidental sensor damage through roadwork

6.2.28.1 Design

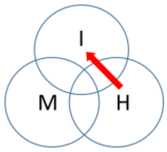
The presence of expensive electronic equipment (sensors) buried under the asphalt layer of a city street requires close coordination between city departments and other service providers. The fact that the devices exist needs to be considered when performing general road repairs, road resurfacing activities, and with the placement of trash containers that are issued by another service provider who is contracted by the city. The requirement of usability (in this case Material Agency) places constraints on existing work and maintenance plans (in this case Interpretive Schema):



6.2.28.2 Realized behaviour and UC

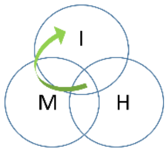
The close coordination between city departments and other service providers, for example with the company that is responsible for placing trash receptacles, proved to be a hurdle – especially at the beginning of the program. In one instance, the city department responsible for road resurfacing was oblivious to the fact that sensors had already been placed in a street and accidentally destroyed approximately 50 devices when breaking open the asphalt for general road resurfacing activities. In another incident, the city department for waste management authorized the waste management service provider to place large recycling receptacles on one stretch of a city street that was already equipped with sensors, thereby rendering them useless.

In both cases, Material Agency, i.e., functioning sensors were in place, but previously drafted work plans for resurfacing or trash receptor placements did not take this into account, causing a conflict between human action (H) and the Interpretive Schema of the work plans (I):

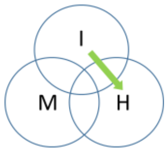


6.2.28.3 Design change or opportunity

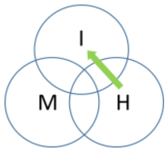
The administrative department responsible for parking and the implementation of new sensor technology exchanged information within the Santander city administration. The topic of the exact location of sensor placements was also raised in city council meetings and other forums to increase general awareness of where sensitive electronic equipment is buried under the asphalt. This human intervention modified the city's rule set so that sensors were protected in the future:



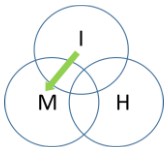
In the first instantiation, city officials were made aware of the existing rule set:



Next, existing rules for sensor placement were revised:



Then, these altered rules (and the placement of sensors) are considered during road repairs:

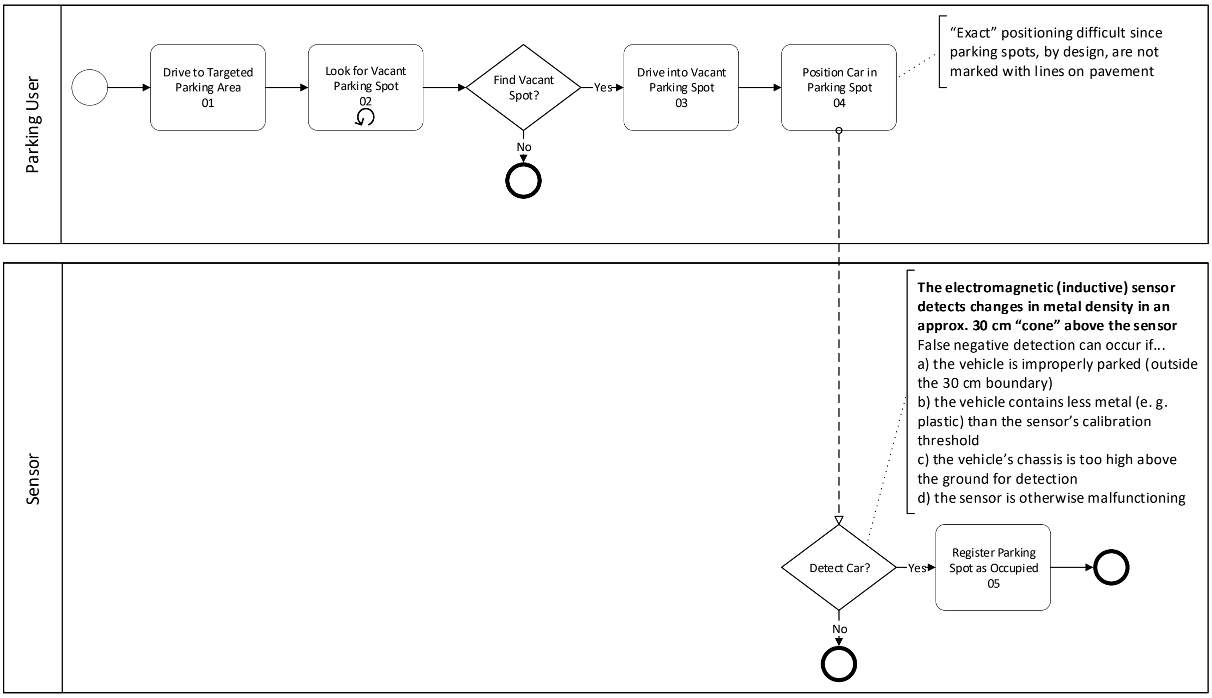


6.2.29 Key finding: Exposed sensors are a tripping hazard – UC: Unsafe sensor exposure

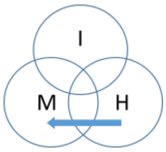
6.2.29.1 Design

Sensors are designed to be below the asphalt and to pick up objects placed upon them in Process 04:

Process 04 — Park Car



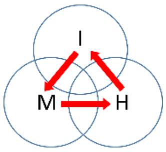
All process steps lead from selecting a spot and parking a car (Steps 01-04, circle H) to its registration in the database (Step 05, circle M):



6.2.29.2 Realized behaviour and UC

Exposed sensors due to road construction, washed-away asphalt, or other occurrences are presenting a tripping hazard and therefore an unsafe situation. The outright anger of Informant R10 became apparent when she was asked how often she has used the parking system in the past month: "*I used to use it. Now I'm fed up.*" Informant R10 continued … "*[The System] works well. The problem is with the sensors – they are not safe. You walk on the street and fall over them. The city was stupid in doing this. Why are the sensors going above the street? They are dangerous. You walk in the street and stumble over them. Make it better or I want no part in this.*"

Several of the interviewed users expressed frustration about the hardware of the system not being properly maintained. The faulty infrastructure (circle M) affects people's personal routines (circle H), but even more so, the persistent system shortcomings seem to be setting an informal rule across the user base (circle I) to complain and for some people to avoid it:



An exposed sensor may or may not fulfil its intended design since ‘exposure’ does not automatically translate to ‘malfunctioning’. However, an exposed sensor in all likelihood poses a hazard:

Whenever < car is parked in the street

If < metal object is placed above the sensor

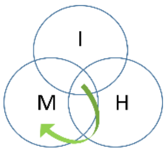
Then < system

Is < must

To Do < record space as ‘occupied’

6.2.29.3 Design change or opportunity

The answer to this problem is clear in that infrastructure, in this case sensors, needs to be properly maintained. The city risks frustrating the users and turning them against using the system:

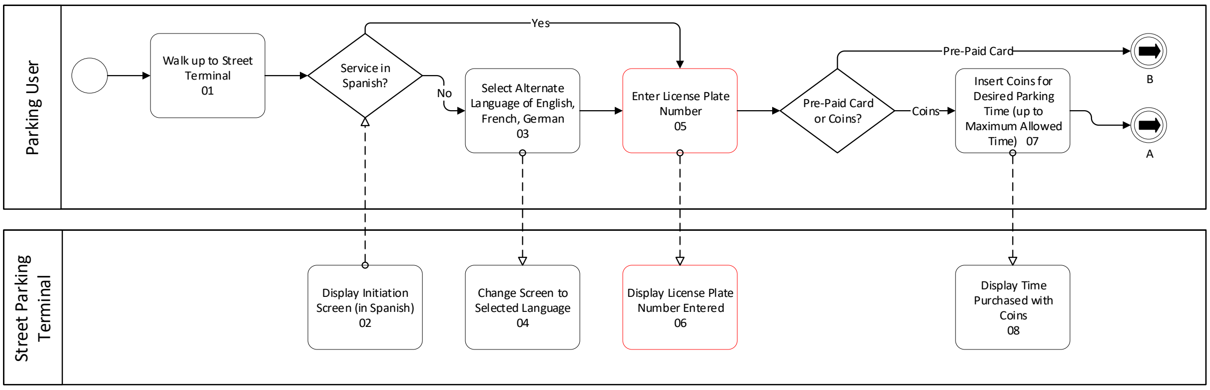


6.2.30 Key finding: Broken parking terminals that are not being replaced quickly – UC: Person uses alternate system (bus)

6.2.30.1 Design

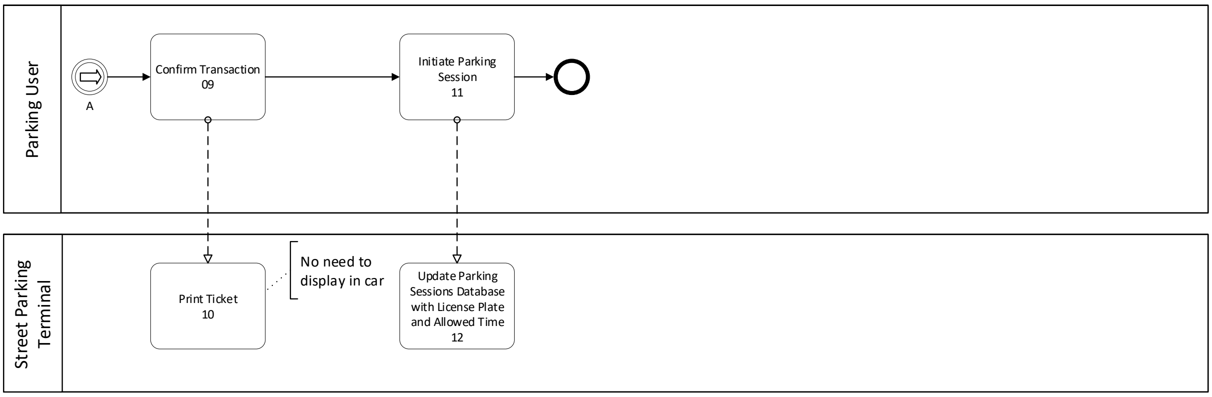
The user has a choice between paying for a parking spot via the Smart Santander application or by walking up directly to a parking terminal for payment:

Process 08 — Initiate Parking Session with Street Parking Terminal



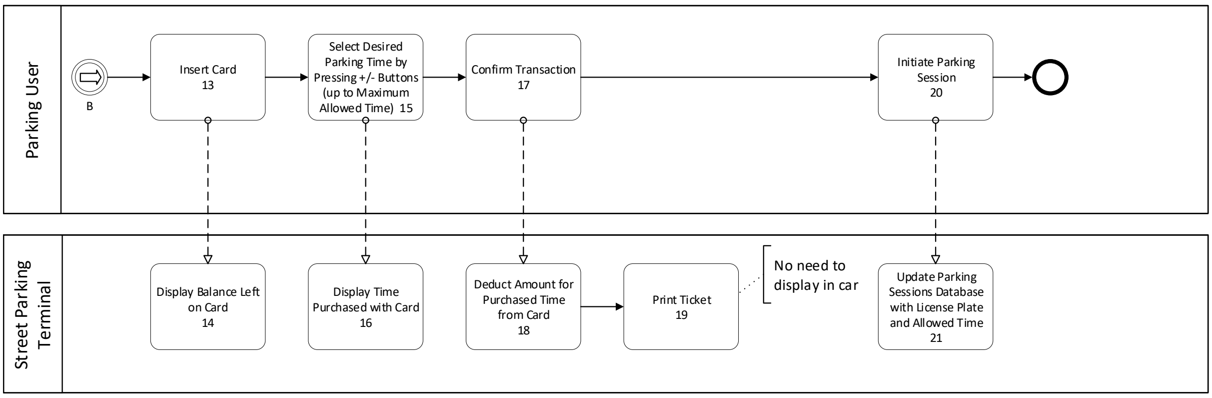
The process is laid out where the person walks up to the terminal (Step 01), makes the appropriate selections on the screen (Steps 02, 04-06) and submits payment (Step 07), where then the parking time is displayed (Step 08).

Process 08 — Initiate Parking Session with Street Parking Terminal



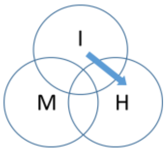
After confirming the transaction (Step 09), the ticket is printed (Step 10), and the parking session initiates (Steps 11 and 12). In case the person selected payment via credit card, the process flow branches off as follows:

Process 08 — Initiate Parking Session with Street Parking Terminal



The user inserts the card (Step 13) and follows the sequence to process payment (Steps 15-19), at which time the parking session initiates in Steps 20 and 21.

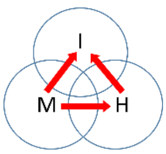
The design of the system (circle I) enables the user (circle H) to satisfy the payment requirement:



6.2.30.2 Realized behaviour and UC

The requirement for payment can only be satisfied if the parking terminal works correctly. When it does not, the user has a choice to either pay through the Smart Santander application (if s/he has previously created a profile), not pay at all, or choose a different parking space that is serviced by a working terminal. Not paying could lead to a fine if the parking administrator does not have a record of the problem of the broken machine. If a parking ticket is issued, the driver still has the option to contest the fine with the argument that the terminal was broken, but this is time consuming. The dilemma of not being able to pay via the parking terminal was expressed by Informant R4 when asked how often he has used the parking system in the past month: *"I use it whenever the terminal works."* – Informant R4 expanded: *"I don't use the app but prefer to pay at the parking terminal directly. Except when it's broken. The city is slow in repairing these. When it's broken, I don't pay and I park for free, which would be good. But when the enforcers don't know that the machine is broken, and I get a ticket. Then, I have to go and complain and spend all this time so that the ticket will be taken away and so that I don't have to pay [the fine]. I prefer to take the bus."*

The user is clearly frustrated with the parking system when it does not work, prefers an alternate solution, and thereby avoids using the system. The problem of the non-functioning parking terminal (M) has significant downstream effects: First, in that it influences the disposition of the user (H) as well as the rule set where an erroneous parking ticket is generated (I). There is also a downstream effect from the individual behaviour (H) in that alternate transportation is sought (I):



The system is designed to perform the following:

Whenever < user choses to pay via parking terminal

If < payment is rendered

Then < system

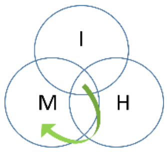
Is < must

To Do < record payment as successful

In this case, the malfunctioning of the payment terminal does not allow for any of the process steps to be executed.

6.2.30.3 Design change or opportunity

The parking administrator would have to repair or replace the system (Material Agency):



While Dornier, the parking administrator, attempts to repair or replace parking terminals as quickly as possible, the availability of spare parts and technicians can cause a delay. In addition, it would be valuable for the Smart Santander app to be equipped to report a broken payment terminal.

6.3 Summarization of findings

“Use better technology that takes into account all participants.” (Informant R9)

The case study interviews yielded 30 findings, summarized in Table 6.1, with the following columns:

Design – with a brief expectation

Realized Behaviour – contrasts the actual behaviour or outcome with the expectation such as the design

Design Norm/Rule – the essence of the applied rule in the finding

P/S – separates between a **P**rocess or **S**trategy related finding: ‘P’ identifies an unintended consequence that is directly attributable to one or more process steps and ‘S’ is a higher-level or conceptual mismatch that does not relate to a given process or to steps within a process

UC – states the unintended consequence

UC Type – assigns the former to a specific category as a higher-level grouping, for example Usage Avoidance, Design Limitation, Quality Limitation, etc.

UC Out(come) – shows the result of the UC that was isolated during the analysis: Trust Erosion (TE), Safety Issue (SI), and Profit Erosion (PE)

Sec – contains the section number with the detailed description and analysis of the UC

Pathways – lists which arrow(s) in the Sociotechnical Behavioural Framework is (are) found to be at issue

Table 6.1 — Summary of findings of unintended consequences

Design	Realized Behaviour	Design Norm/Rule	P/S	UC	UC Type	UC Out	Sec	Pathways (Arrows)
Project team envisioned swift user adoption	Users resisted adoption/felt excluded during planning	Active user participation facilitates system ownership	S	User non-involvement fostered resentment	Usage Avoidance	TE	6.2.1	Arrow 2 and 3
Sensors must be placed under ground	Sensor installation more costly than orig. anticipated	Accuracy of financial cost plans	S	Project cost exceeds estimate	Design Limitation	PE	6.2.2	Arrow 5 and 6
City planning to account for sufficient parking	Actual number of spaces turned out to be insufficient	One available space for each resident or visitor parking user	S	General parking space unavailability	Design Limitation	TE	6.2.3	Arrow 2 and 5
Cameras are more accurate than sensors	City decided to implement sensor-based system	Improve system accuracy through camera usage	S	Expected parking space unavailable	Quality Limitation	TE	6.2.4	Arrow 2 and 4
Cameras are technically superior to sensors	Spain’s strict privacy law does not allow usage of cameras	Local law mandates use of magnetic sensors in street	S	Expected parking space unavailable	Design Limitation	TE	6.2.5	Arrow 1 and 6
Users are expected to pay for parking	Some users do not pay for parking (‘free rider syndrome’)	Service is rendered for fee paid	S	Anonymity of system is conducive to cheating	Design Limitation	PE	6.2.6	Arrow 4
Paid parking is in effect during pre-defined times	Users disagree with having to pay	Car parked during ‘paid times’ requires payment	S	Perceived unfairness changes behaviour	Design Limitation	TE	6.2.7	Arrow 1

Table 6.1 — Summary of findings of unintended consequences

Design	Realized Behaviour	Design Norm/Rule	P/S	UC	UC Type	UC Out	Sec	Pathways (Arrows)
	when spots are empty							
Installation of sensors was exp. to be transparent	Citizen routine disrupted, neg. business impact, congestion incr.	Do disruptive work during off-hours, announce changes	S	Disruption of routine causes frustration	Design Limitation	TE	6.2.8	Arrow 2
Project team envisioned swift user adoption	Users resisted adoption due to confusion with unrelated mods.	Informed users allow for better system adoption	S	Unrelated fee increase caused user resentment	Usage Avoidance	TE	6.2.9	Arrow 2
Parking zone delineation to match traffic patterns	Zones/traffic are out of balance causing over- or underpayment	Rates for zones are dynamically calculated due to traffic patterns	S	Users unfairly pay too little or too much for parking	Design Limitation	TE	6.2.10	Arrow 2 and 5
Competition of providers supports innovation	Fin. incentives cause unhealthy competitive practices	Maximize profit through competition	S	Service provider's proposals are unrealistic	Design Limitation	TE	6.2.11	Arrow 2 and 3
Profit tied to total no. of parking spaces	Roadwork makes some parking spaces unavailable	Available space + parked car = profit for provider	S	Unscheduled roadwork decreases profit	Design Limitation	PE	6.2.12	Arrow 5 and 6
Service providers must also be technologists	Now subset of companies unable to compete	Managers and staff cannot make transition to technology	S	Smaller pool of potential service providers	Design Limitation	PE	6.2.13	Arrow 2 and 3
Parking spot selection needs user attention	Parking spot selection not possible while driving	Normal system design	P	Expected parking space unavailable	Design Limitation	TE	6.2.14	Arrow 5

Table 6.1 — Summary of findings of unintended consequences

Design	Realized Behaviour	Design Norm/Rule	P/S	UC	UC Type	UC Out	Sec	Pathways (Arrows)
Parking spot can only be viewed, not reserved	Space no longer available upon car's arrival	Normal system design	P	Expected parking space unavailable	Design Limitation	TE	6.2.15	Arrow 5
Car must be placed above sensor to register	Inexact parking causes sensor not to register (worse without painted lines)	When car is parked above sensor, system registers space as 'occupied'	P	Expected parking space unavailable	Design Limitation	TE	6.2.16	Arrow 1 and 4 and 5
Car must be placed above sensor to register	Large number of broken sensors not replaced quickly	When car is parked above sensor, system registers space as 'occupied'	P	Expected parking space unavailable	Usage Avoidance	TE	6.2.17	Arrow 1 and 4
Car must be placed above sensor to register	People are deliberately destroying sensors	When car is parked above sensor, system registers space as 'occupied'	P	Expected parking space unavailable	Design Limitation	TE	6.2.18	Arrow 3
Car must be placed above sensor to register	Motorcycles do not always trigger the sensor	When object is parked above sensor, system registers space as 'occupied'	P	Expected parking space unavailable	Design Limitation	TE	6.2.19	Arrow 1 and 4
User enters lic. plate in terminal	User enters incorrect lic. Plate	Wrong lic. plate entry causes fine	P	User frustrated by fine	Usage Avoidance	TE	6.2.20	Arrow 5
User selects lic. plate record in app	User selects wrong lic. plate record	Wrong lic. plate entry causes fine	P	User frustrated by fine	Usage Avoidance	TE	6.2.21	Arrow 3
Scanning vehicles patrol streets	User not paying, attempting to leave quickly	Unpaid parking causes fine	P	User outruns scanning vehicle to avoid fine	Unsafe Usage	SI	6.2.22	Arrow 1 and 3
Scanning vehicles most	Busy streets impede	Normal system design:	P	Drop in scanning	Affordance Limitation	PE	6.2.23	Arrow 1 and 3

Table 6.1 — Summary of findings of unintended consequences

Design	Realized Behaviour	Design Norm/Rule	P/S	UC	UC Type	UC Out	Sec	Pathways (Arrows)
efficient in continuous operation	efficiency of scanning vehicles	Scanning vehicle must stop and wait at obstruction		vehicle efficiency				
System restricts parking in the same spot to two hours maximum	People who want to park longer must move their car to a different spot (different street)	Enable max. parking opportunities for residents and visitors	P	Two-hour parking maximum alters behaviour	Design Limitation	TE	6.2.24	Arrow 2
Most streets (80%) are served by automated scanners	People do not pay for parking or overstay the purchased parking time	Automation is regarded as more efficient than manual street patrolling	P	Delayed compliance checks conducive to rule breaking	Affordance Limitation	PE	6.2.25	Arrow 1
Car must be placed above sensor to register	First generation sensor had sub-standard metal detection ability	When car is parked above sensor, system registers space as ‘occupied’	P	Sensor quality failure	Quality Limitation	TE	6.2.26	Arrow 6
Street disp. Panels direct drivers	Malfunctioning panels caused service outage	User has option to direct car to available area(s)	P	Panel quality failure	Quality Limitation	TE	6.2.27	Arrow 1 and 4
Uninterrupted sensor signal requires continued operation	Uncoordinated roadwork disrupted sensor functioning	All departments in the city must be aware of sensor existence and operations	P	Accidental sensor damage through roadwork	Design Limitation	PE	6.2.28	Arrow 1
Sensors are designed to be below asphalt	Exposed sensors are a tripping hazard	Sensors are meant to be invisible in the street	P	Unsafe sensor exposure	Unsafe Usage	SI	6.2.29	Arrow 1 and 4 and 5

Table 6.1 — Summary of findings of unintended consequences								
Design	**Realized Behaviour**	**Design Norm/Rule**	**P/S**	**UC**	**UC Type**	**UC Out**	**Sec**	**Pathways (Arrows)**
Payment requires functioning terminal	Non-working terminal does not allow user to pay	Payment rendered at place and time of parking	P	Person uses alternate system (bus)	Quality Limitation	TE	6.2.30	Arrow 1 and 4 and 6

The detailed findings are subsequently summarized into higher level groupings that correspond to the columns in Table 6.1.

6.3.1 Process related versus strategy related findings

The results of the case study fall into two major groupings that are reflected in the P/S column within the summary table. There are process related findings (expressed through the marker 'P') and strategy related findings (expressed through the marker 'S').

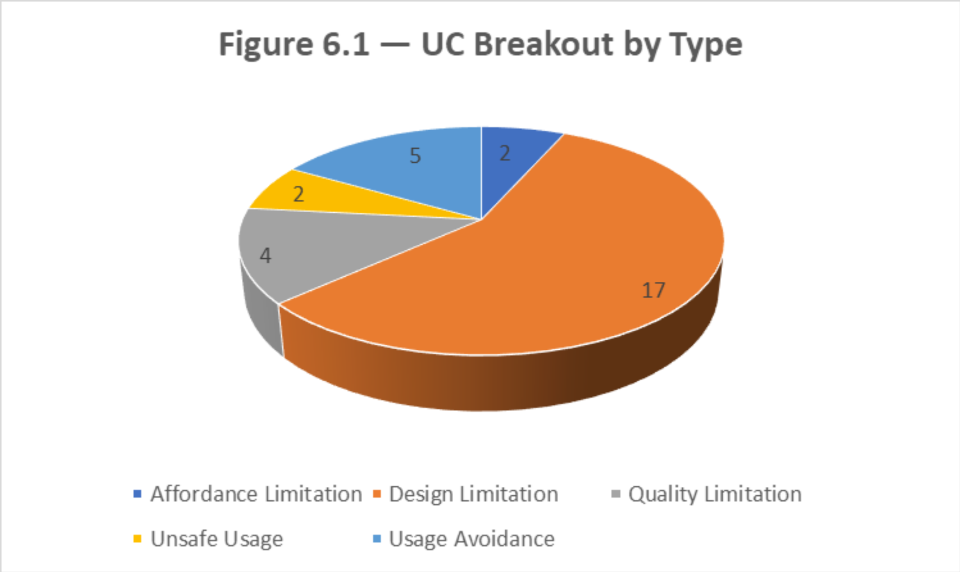
The former identifies a UC that is directly attributable to one or more process steps where these were not executed as expected. DeSanctis and Poole (1994: 129-130) refer to such an occurrence as an unfaithful process execution with the root cause being an error (misperception, lack of understanding, and slippage) or intentional unfaithful usage, such as sabotage, inertia, and innovation (Orlikowski, 2000: 409).

Strategy related findings (marker 'S') cannot be directly assigned to a process or to steps within a process. These relate to higher-level and conceptual mismatches between the intended and realized situation. An example of this type of finding is that the City of Santander changed their procurement requirements as part of the Smart City initiative. Solution providers are now expected to provide the technical solution in addition to the product and service, which has led to unhealthy competitive practices among the solution providers. This issue applies to the entire program and is therefore not contained to a particular process or step that could be altered to alleviate any negative effects.

The 30 findings contain 17 relating to process specific issues and 13 relating to strategy issues.

6.3.2 Type of unintended consequence

Figure 6.1 lists five summary categories of UCs that were identified during data analysis:



6.3.2.1 Design limitation

By far the largest part (17 findings or 57%) relate to limitations in the design that in turn lead to one or more unintended effects. In referring to DeSanctis and Poole's (1994: 129-130) division between unfaithful process execution and unfaithful usage, these are as follows (the section number of each of the 17 findings is in parentheses).

Misperception: Sensor installation was more disruptive (6.2.8) and more costly (6.2.2) than originally anticipated.

Lack of understanding: Actual number of spaces provisioned turned out to be insufficient (6.2.3), roadwork affects availability of parking spaces (6.2.12), two-hour parking limit forces users to change parking spots (6.2.24), and drivers voiced their disagreement when having to pay during times when many spots are empty (6.2.7).

Slippage: Uncoordinated roadwork disrupted sensor functioning (6.2.28).

Sabotage: People are deliberately destroying sensors (6.2.18).

Inertia: Some users do not pay for parking in a 'free rider syndrome' (6.2.6), zones and traffic volume are out of balance causing over- or underpayment (6.2.10).

Innovation: Parking spot selection is not possible while driving (6.2.14), parking space is no longer available upon a car's arrival (6.2.15), inexact parking causes sensor not to register (6.2.16), Spain's privacy law prevents usage of cameras (6.2.5), financial incentives cause unhealthy competitive practices (6.2.11), subset of companies is unable to compete (6.2.13), and motorcycles do not always trigger the sensor (6.2.19).

6.3.2.2 Usage avoidance

Five findings (17%) strongly related to users rejecting the system and not wanting to participate in the Smart City/Smart Parking initiative. Four of the five findings contained an element of unfairness and exclusion where the user felt that they were not treated fairly and/or that they were excluded from the process altogether:

Section 6.2.1 describes the expectation of the project team that residents and visitors in the city would adopt the new technology quickly. However, several individuals who provided feedback voiced their frustration of not having been included during the planning and design phase of the initiative.

Section 6.2.9 describes the issue where the city increased parking fees at the time of the Smart Parking implementation. According to project participants, this fee increase was not a result of the system introduction but took place, coincidentally, at the same time. The user community reacted adversely since people connected these two unrelated actions. As a result, people avoided using the system since it was 'blamed' for the price increase.

Two findings deal with users entering incorrect data in the parking terminal (Section 6.2.20) and the Smart Santander application (Section 6.2.21). In these cases, the mistake results in the user receiving a parking fine, which in turn has caused people not to use the system going forward.

Lastly, Section 6.2.17, expresses the resident's frustration when broken sensors are not replaced quickly. The sentiment of 'the city is not doing what it is supposed to do' has also caused people to turn away from using the system.

6.3.2.3 Quality limitation

The four findings (= 13%) in this category are not directly related to UCs of using the system. These are rather occurrences where the quality of the technical solution does not fulfil the expectations of the design. The resulting consequences are therefore not unintended within the context of a human and technology interaction, but they are still noteworthy since they underline the importance of quality assurance as well as quality control and testing. In addition, all four were reported by users to have eroded trust in the system, thus indirectly influencing system usage.

By far the costliest issue for the city was the fact that the first generation of sensors had sub-standard metal detection abilities (Section 6.2.26). After the sensors were installed, by breaking open the asphalt and afterwards resealing the surface, it became apparent that the constant error rate simply remained too high. The failure relates particularly to the first-generation sensor's inability to register a parking space as 'occupied' when a car was parked above.

The second quality-related finding in Section 6.2.27 concerned a high occurrence of malfunctioning street display panels. The problem was subsequently traced to water ingress into the panel that disturbed the electronic mechanisms inside the panel.

Section 6.2.30 describes an interview with a user who complains about parking terminals in the street that are not working. This quality issues prevents the user from paying for a parking space. However, parking tickets could still be issued since there is no apparent feedback loop between a broken parking terminal and the detection mechanism for wrongful users of the system. The burden of proof remains with the user, which causes frustration and trust issues. Informant R4 summarized the problem as follows: *"[…] I have to go and complain and spend all this time so that the ticket will be taken away and so that I don't have to pay [the fine]. I prefer to take the bus."*

Many cities who implement Smart Parking solutions now opt for the more modern camera-based system. The accuracy of detecting a parked car and recognizing its license plate number is significantly higher than with the outdated sensor-based system. Residents in Santander, particularly individuals who are informed about Smart City developments, recognize this, and have expressed resentment for having to deal with an outdated technological solution (see Section 6.2.4).

These four quality-related findings contribute to an eroding trust in the system, which in turn affects system usage.

6.3.2.4 Affordance limitation

This grouping contains two findings (= 7%) where both relate to the larger issue of infrastructure affordance. The first relates to the affordance of physical space in the street, and the latter to the fact that machines are different from humans and therefore trigger a fundamentally different response from another human: the human-machine interaction is, by default, different from the human-human interaction.

The finding that is described in Section 6.2.23 records that busy streets impede the efficiency of scanning vehicles. The street only affords a limited space that cannot easily be increased through a design change. In addition, it is difficult to regulate the flow of cars into a street, barring the closure of the entire street to traffic. The affordance of the available space thereby imposes a boundary for activities in the street. The scanning vehicle reading license plates is one of many participants in street traffic. Its advancement, and therefore efficiency, is directly tied to the traffic volume around it. Whenever the scanning vehicle encounters an obstruction, such as a stopped car in front of it, it must stop as well. There is an inverse relationship between traffic volume within a given street and efficiency of the scanning vehicle.

The example of a basic human affordance that cannot be remedied through a system design change is elaborated on in Section 6.2.25. As the interviewee described it, in a human-to-human interaction the threshold not to follow a rule is higher than in a human-to-machine interaction where the machine does not have a ‘conscience’. The premise brought forward in the interview is that automated scanning vehicles can activate a lower human desire to follow rules than if the same humans encountered a human patrol officer. The willingness to break a rule seems to be higher when the control mechanism is a machine. Since the city and service provider monitor 80% of the streets of Santander through automated scanning vehicles, most interactions that depend on using the system honestly, rely on human-machine encounters that have a lower threshold for breaking the rule.

The observed effect of both findings has been a decrease in efficiency.

6.3.2.5 Unsafe usage

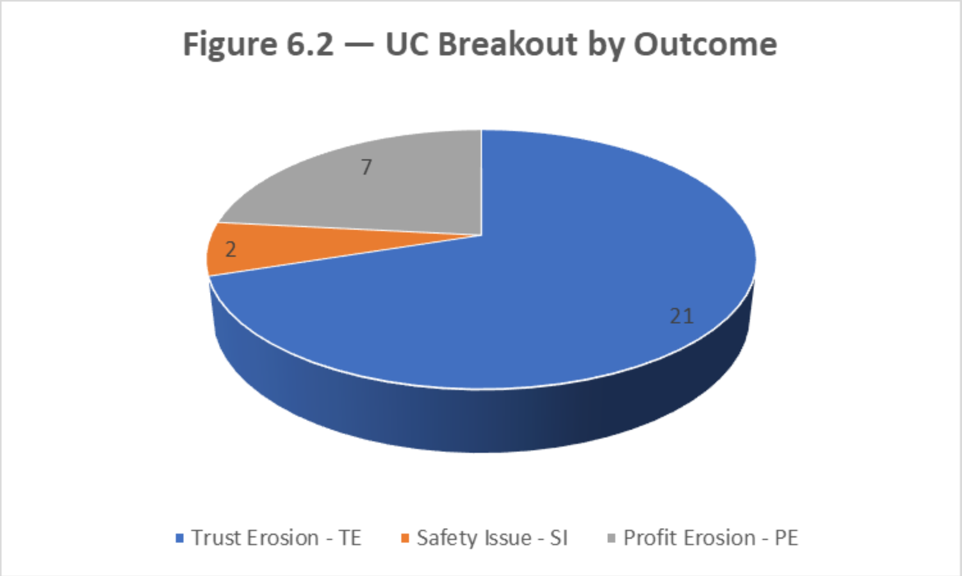
This last grouping of UCs also contains two findings, representing 7% of the total findings. The first relates to Human Agency (circle H of the SBF) and the second relates to Material Agency (circle M).

Section 6.2.22 describes the case where people who parked their cars try to move their cars quickly in sight of an approaching scanning vehicle. This is conceivably the case when the user parked the car and did not pay – or when the allotted parking time has expired. The fact that people run towards their parked cars, often within a busy street, has caused accidents or near accidents.

Section 6.2.29 recorded the finding where exposed sensors can pose a tripping hazard. The interviewee was previously injured and resented the perceived “lack of care” displayed by the city.

6.3.3 Outcome of unintended consequence

Figure 6.2 depicts three outcomes that emerged from the data:



6.3.3.1 Trust erosion (TE)

By far the largest observed problem is an erosion of trust that occurs when using the system. Out of these 21 findings, the majority (12) relate to limitations in the system design that are incongruent with the user's expectations. The identified problems span from macro to micro issues throughout the design:

Limitations in the regulatory framework – e. g. Spain's strict data privacy law currently does not allow for a more advanced solution with cameras, mismatch between zones and traffic volume cause space shortages and oversupply in different areas.

Perception issues of 'unfairness' – e. g. users disagree with the concept of paying for parking if there is no apparent shortage of parking spaces, people are frustrated by malfunctioning equipment that is not repaired by the city or the service provider, and – from a supplier's perspective – financial incentives that cause unhealthy competitive practices.

General usability or convenience shortcomings – e. g. insufficient overall number of parking spaces, installation of sensors creates an annoyance, parking spot selection is not possible while driving, parking space may not be available upon arrival, requirement to change spots when wanting to park longer than two hours during peak times.

Technical calibration issues – e. g. sensors do not pick up parked cars or motorbikes that are parked in an inexact fashion.

In addition to these 12 system design issues, there are 4 effects resulting from quality problems that were expanded upon in Section 6.3.2.3 – e. g. previous sensor generation could not pick up a lower metal density, malfunctioning street panels, broken parking terminals, and other technical shortcomings resulting from a sensor-based system rather than installed cameras.

6.3.3.2 Profit erosion (PE)

Seven findings pertain to an erosion of profit across three different stakeholder groups:

Service Provider (Dornier) – with the installation of sensors having been more costly than originally anticipated, scheduled roadwork causing some parking areas to be temporarily 'off the grid' without the possibility to generate revenue, and some users not paying for parking ('free riders').

City – where underground sensors were damaged due to uncoordinated roadwork (the city later reimbursed Dornier for the damage caused and thereby suffered a negative financial impact).

Potential future vendors – by the requirement for service providers to now also handle the technical implementation that makes it difficult for 'non-technologists' to compete.

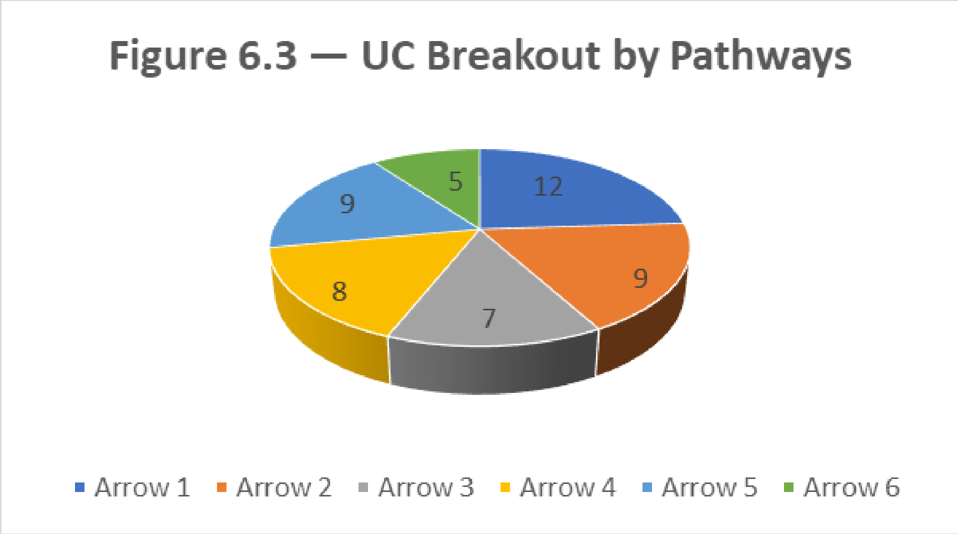
6.3.3.3 Safety issue (SI)

Two findings are issues that result from user's unsafe behaviour: Users outrunning scanning vehicles to avoid a fine (see Section 6.2.22) and unsafe exposure of sensors in the streets (see Section 6.2.29).

6.3.4 Pathways of the Sociotechnical Behavioural Framework

This section maps the individual findings to each of the nine arrows (pathways) of the SBF. In doing this, the analysis provides the basis for answering the second research sub-question: *"What are the potential generative mechanisms behind unintended consequences and how can we model them?"* Each finding relates to one or more issues that are reflected in arrows 1 through 6. This can be a one-to-many relationship since more than one framework pathway can contribute to a UC.

For issues expressed in arrows 1 through 6, the data shows that each of the framework's pathways contributed, with varying frequency, to the UCs experienced in Santander. The findings show as few as 5 issues for pathway 6 (Material Agency influencing Interpretive Schema) and as many as 12 issues for pathway 1 (Human Agency influencing Interpretive Schema). The detailed counts are shown in Figure 6.3:



6.4 Further analysis of unintended consequences

"Nothing is as practical as a good theory." (Lewin, 1945: 129)

This section explores the generative mechanisms of the previously identified UCs with suggestions as to their causality. The work highlights possible recommendations by using the SBF to identify how the framework could be used in praxis to alleviate the problems that were experienced in Santander. It does this by juxtaposing the Context, Mechanism, and Outcome (Pawson and Tilley, 1997). This C-M-O analysis has previously been employed by Dobson *et al.* (2013: 981-984) in a study rooted in Analytical Dualism and morphogenesis.

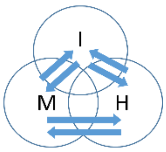
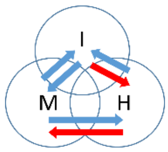
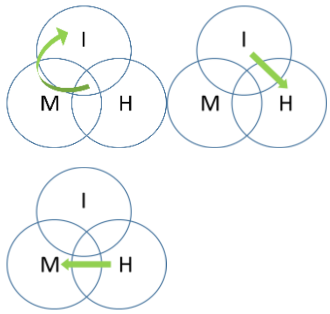
6.4.1 SBF link to Context – Mechanism – Outcome (C-M-O) Analysis and time-phased morphogenetic view of UCs

The analysis starts out with a brief 'side by side' review of the SBF pathways. For the realized behaviour of the finding, it adds the C-M-O configuration where the context, mechanism, and outcome are arranged next to each other. This is done as an aid to deconstruct the imbrication to get to systemic structural elaborations (see Figure 3.3 in Section 3.1.2.1).

The third part of the analysis is a time phased morphogenetic view of the UC across the dimensions of pre-existing structure, action, and structural elaboration (Archer, 2010: 238).

6.4.1.1 UC: User non-involvement fostered resentment

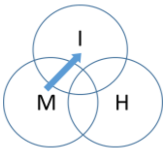
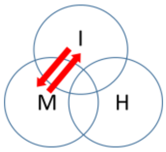
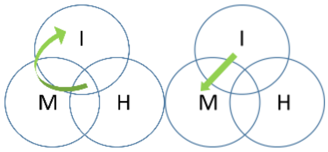
SBF View		
Design	**Realized Behaviour**	**Design Change**

		
Users contribute to design, it is transposed into the system's behaviour, provides functionality to the user, user accepts rules imposed by the system, design is open to system's affordances, humans are using the system for their benefit and moderated by its affordances.	Design was to a large degree rejected by users who in turn did not use the system as intended	Communication improved understanding of the system and positively affected usage of technology
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Early user involvement is an important aspect for system adoption after roll-out	Insufficient (early) user involvement by the project team	System was rejected by many residents leading to Trust Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Design was largely completed by the project team	User input was gathered through focus groups	Design was adjusted to better confirm with user's expectations
M	Functionality of the system reflected the original design		System behaviour changed based on the new design

H	Users resented the solution due to lack of consultation in the beginning		System adoption rate increased

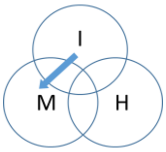
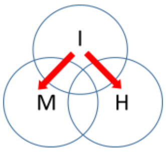
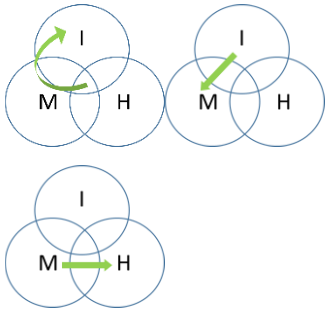
6.4.1.2 UC: Project cost exceeds estimate

SBF View		
Design	**Realized Behaviour**	**Design Change**
		
Parking sensors are designed to be buried under asphalt	Sensor installation greatly exceeded cost estimate	Financial plans revised with more realistic planning assumptions to purchase equipment
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Original project cost estimate was constructed with unrealistic assumptions	Exceeded cost estimates due to underground sensor installation	Profit Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Original (wrong) project cost estimate	Project cost estimate revised with adjusted planning assumptions	Adjusted (more realistic) project cost estimate
M	Sensors need to be installed under road surface		No Change

H	N/A		N/A

6.4.1.3 UC: General parking space unavailability

SBF View		
Design	**Realized Behaviour**	**Design Change**
		
The city initially estimated required resident and visitor spaces	Estimate for residents too low, resulting in resident parking shortage	City plans to switch to quarterly resident pass allocation
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Allocation between residents (frequent users) and one-time visitors is set annually	Seasonality affecting space requirements and leading to shortages	Lack of parking spaces, rejection of the system → Trust Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Estimation for resident and visitor parking is done annually	Switch estimation of parking spaces from annual to quarterly to take seasonality into account	Estimation occurs quarterly and takes seasonality into account
M	Parking spaces for residents and visitors are assigned annually		Spaces are assigned quarterly

H	Shortage of parking spaces (especially for residents) causes frustration		Severe parking space shortage for residents (and visitors) is alleviated

6.4.1.4 UC: Expected parking space unavailable

This UC seems to be the biggest issue in Santander's Smart Parking program. The unavailability, upon the driver's arrival, of a previously expected parking space was reflected in eight findings:

City decided to implement sensor-based system (see Section 6.2.4)

Spain's strict privacy law does not allow usage of cameras (see Section 6.2.5)

Parking spot selection not possible while driving (see Section 6.2.14)

Space no longer available upon car's arrival (see Section 6.2.15)

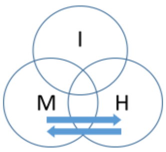
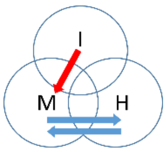
Inexact parking causes sensor not to register (see Section 6.2.16)

Large number of broken sensors not replaced quickly (see Section 6.2.17)

People are deliberately destroying sensors (see Section 6.2.18)

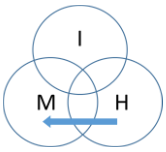
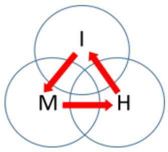
Motorcycles do not always trigger the sensor (see Section 6.2.19)

One key issue is the circumstance that the Smart Santander parking application does not allow the user to reserve a parking spot ahead of time. Once the person is in the car, it is virtually impossible to constantly check for available spots via the application where the space situation can change in an instant. The absence of a reservation function means that availability and unavailability of a parking space is largely coincidental, which makes the system unreliable.

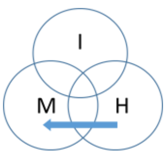
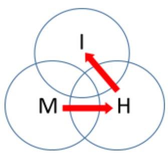
SBF View	
Design	**Realized Behaviour**
	

The system's affordance is constrained by the user's inability to drive while looking at the application	The design of the application does not accept reservation for a physical parking space

Another large problem that causes trust issues with the system is brought on by users parking their cars outside of the sensor's reach. What adds to the issue of inexact parking is the fact that the designers opted for not aiding users with painted stripes on the pavement. These would indicate where the car must be parked for it to be correctly placed within the activity field of the sensor. While the city and service provider have a reason for not painting lines, i.e., for keeping parking space delineations flexible, and therefore to accommodate more cars, the negative effect is nevertheless an inexact reading of parking space occupation.

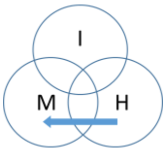
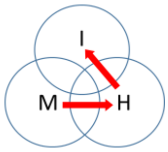
SBF View	
Design	**Realized Behaviour**
	
Humans are expected to conform to the affordance of the sensor	The system's technical limitation causes the user to be non-conforming and causing an incorrect availability picture and leading to a trust issue

A variant of this issue is the parking of motorbikes in that they are often not placed above the sensor with the required precision for the system to register their presence. This causes for the parking space to be registered as 'available' to others when in fact it is not.

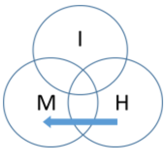
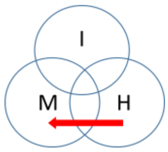
SBF View	
Design	**Realized Behaviour**
	

Humans are expected to conform to the affordance of the sensor	The system’s technical limitation causes the user to be non-conforming and leading to an incorrect availability picture

The lack of basic system maintenance was found to be another contributor to eroding trust in the system. More specifically, it is the replacement of broken sensors that is not performed by the city in a timely manner. The pathways in the framework here are identical with the previous issue of users parking in an inexact fashion so that they are outside the range of the sensor:

SBF View	
Design	**Realized Behaviour**
	
Humans park the car in the spot and above a sensor	The non-functioning sensor results in an inexact parking space availability picture that causes mistrust in the system that becomes systemic across more users

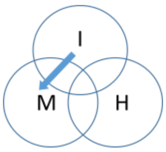
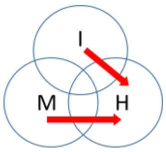
One tributary to the non-functioning sensors is the occurrence of vandalism where people destroy sensors deliberately. For this to take place, they will have had to be exposed in the asphalt.

SBF View	
Design	**Realized Behaviour**
	
City planners and operators expect for users to operate the system as per its affordances	Humans then tamper with the functionality of the system

The wilful destruction of sensors has been a significant problem for the city. It is difficult, if not impossible, to establish causality for the user’s action. One possible viewpoint is that the frustration with the system’s shortcomings has prompted for people to take extreme measures in voicing their opposition to the system. Informant R2 commented: *"It [the system] does not work very well at all. It's quite often that the app says that a space is available, or that many spaces are available, and in the end, another car is parked there or the whole row is full. There are many sensors that are not functioning or not functioning well. The city doesn't replace sensors if they are broken."*

C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Parking spot availability is only accurate 'as of the current moment' in the application and street display panels; space reservation is not possible	Inaccurate capture of parking space availability due to negative affordances, time delays, or non-conforming usage	Trust Erosion

The following two, and last findings relating to this UC, point to the solution that would alleviate the previously described issues where the city decided in 2012 to implement a sensor-based system. In the meantime, camera-based systems have surpassed sensor-based technology in terms of accuracy and reliability. Based on interviews with city planners and the technical team at the University of Cantabria, this change in technology was difficult to anticipate ten years ago, where both technologies (sensors and cameras) were regarded as being equal. In addition, sensors are less expensive than cameras, which also steered the implementation team to opt for sensors.

SBF View	
Design	**Realized Behaviour**
	
General technical considerations, regulatory framework, and cost constraints drove the decision to implement sensors	Obsolete technical design combined with better (camera based) experiences in other cities influence user's attitude

Many residents in Santander seem to be aware that their system is outdated and that it must be revised for it to be successful. The city is currently building a business case that is expected to justify the funding of the system upgrade. The project team anticipates that their educational campaign would be able to convince people that these cameras are not used for inappropriate purposes such as to spy on citizens.

From the standpoint of morphogenesis, this major technical upgrade could be reflected in (most likely) two cycles where the first deals with the approval of the business case and addressing the concerns of data privacy advocates. The second cycle reflects the actual upgrade in technology – after the business case has been approved. It is noticeable that the 'Structural Elaboration' column of the 'Preparatory Work' becomes the 'Pre-existing Structure' column of the 'Implementation Work'.

<u>Preparatory Work</u>

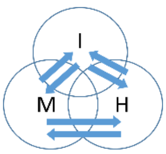
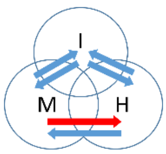
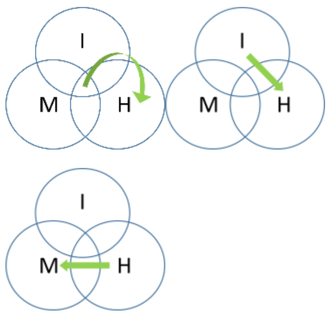
<table>
<tr><th colspan="4">Time-Phased Morphogenetic View</th></tr>
<tr><th>Circle</th><th>Pre-existing Structure</th><th>Action</th><th>Structural Elaboration</th></tr>
<tr><td>I</td><td>Current technical choice (sensors) was set in 2012, inexpensive and non-controversial regarding data privacy</td><td rowspan="3">Use current scepticism and non-adoption of system to argue for the business case to upgrade the system and alleviate concerns of data privacy advocates</td><td>Updated design and implementation plan (approved for cameras)</td></tr>
<tr><td>M</td><td>Sensors are measuring occupancy with sub-standard success rate</td><td>Sensors still in place</td></tr>
<tr><td>H</td><td>Users do not trust the system</td><td>Users to not trust the existing system, but are supportive of future direction since this promises alleviation of problems</td></tr>
</table>

<u>Implementation Work</u>

Time-Phased Morphogenetic View

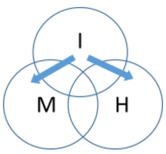
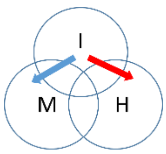
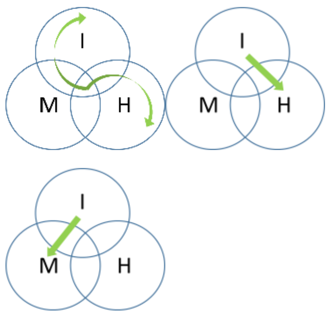
Circle	Pre-existing Structure	Action	Structural Elaboration
I	Updated design and implementation plan (approved for cameras)	Use approved business case to upgrade system to cameras	Camera-based design
M	Sensors still in place		Upgraded to cameras
H	Users to not trust the existing system, but are supportive of future direction since this promises alleviation of problems		Users regain trust in the system (mostly driven by accurate parking space availability picture)

6.4.1.5 UC: Anonymity of system is conducive to cheating

SBF View		
Design	**Realized Behaviour**	**Design Change**
		
Users contribute to the design, it is transposed into the system's behaviour, provides functionality to the user, users accept rules imposed by the system, design is open to system's affordances, humans are using the system for their	Santander experienced the situation where the number of users not paying for parking increased ('free rider syndrome'). It was observed that the absence of a patrol officer contributed to this issue. In this case, the presence of technology	Subsequently, the city appealed to the resident's sense of fairness through a campaign to counteract this trend. Subsequently, the user's payment behaviour improved.

<table>
<tr><td colspan="2">benefit and moderated by its affordances</td><td colspan="2">influenced people’s behaviour</td><td></td></tr>
<tr><th colspan="5">C-M-O View of Realized Behaviour</th></tr>
<tr><th colspan="2">Context +</th><th colspan="2">Mechanism =</th><th>Outcome</th></tr>
<tr><td colspan="2">Anonymity of an automated solution alters people’s behaviour regarding ethics</td><td colspan="2">Increases of non-payment due to non-supervised automation</td><td>Profit Erosion</td></tr>
<tr><th colspan="5">Time-Phased Morphogenetic View</th></tr>
<tr><th>Circle</th><th>Pre-existing Structure</th><th colspan="2">Action</th><th>Structural Elaboration</th></tr>
<tr><td>I</td><td>‘Pay for parking’ rule is in effect</td><td colspan="2" rowspan="3">Campaign that appealed to people’s ‘sense of fairness’</td><td>‘Pay for parking’ rule is still in effect (no change)</td></tr>
<tr><td>M</td><td>N/A</td><td>No change</td></tr>
<tr><td>H</td><td>System implementation led to drop in profit because of non-payment</td><td>Occurrences of non-payment decreased</td></tr>
</table>

6.4.1.6 UC: Disruption of routine causes frustration

<table>
<tr><th colspan="3">SBF View</th></tr>
<tr><th>Design</th><th>Realized Behaviour</th><th>Design Change</th></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Plan foresaw that prep work for system go-live is accepted by users</td><td>Imposition of new rule set was met with resistance against implementation</td><td>Change management should have been considered during roll-out</td></tr>
</table>

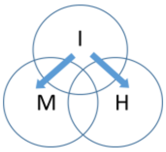
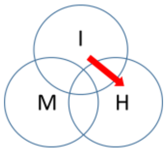
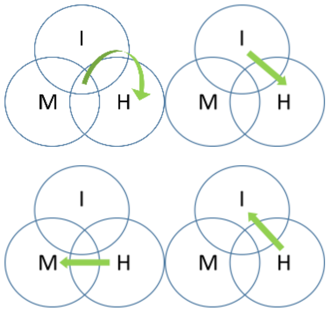
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Understanding the reason(s) for change is paramount for the acceptance of change	Inadequate change management	Strong resentment from residents → Trust Erosion

From a morphogenetic standpoint, the following is a theoretical thought experiment since the project team did not course-correct while the roll-out took place. It is an assumption as to what might have happened if the roll-out had been accompanied by adequate change management initiatives:

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Preliminary system design and roll-out plan is drafted by project team	Change is socialized with all affected stakeholders	Stakeholder input is considered with system design and roll-out plan modifications
M	System is prepared for roll-out, but final implementation configuration is pending final design (row I for Structural Elaboration)		Final system configuration and roll-out occurs according to updated plans
H	Stakeholders are ready to provide input		Stakeholders do provide input that is then considered by the project team

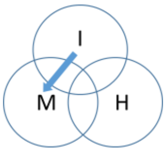
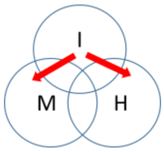
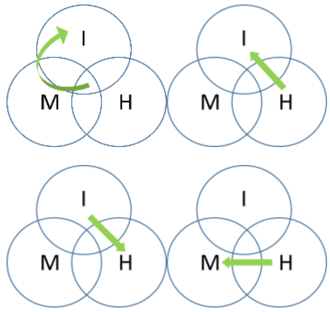
6.4.1.7 UC: Unrelated fee increase caused user resentment

SBF View		
Design	**Realized Behaviour**	**Design Change**

<table>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td>Team thought that design supported affordances and user's expectations</td><td>An unrelated rule set influenced people's acceptance of the system</td><td colspan="2">Project team scrambled to adjust messaging and perception. This in turn influenced general acceptance of the solution and technology</td></tr>
<tr><td colspan="4">C-M-O View of Realized Behaviour</td></tr>
<tr><td>Context +</td><td>Mechanism =</td><td colspan="2">Outcome</td></tr>
<tr><td>People react adversely to unexpected cost increases that are not understood</td><td>Conflation of unrelated events</td><td colspan="2">Trust Erosion</td></tr>
<tr><td colspan="4">Time-Phased Morphogenetic View</td></tr>
<tr><td>Circle</td><td>Pre-existing Structure</td><td>Action</td><td>Structural Elaboration</td></tr>
<tr><td>I</td><td>Two unrelated design elements (new system and cost increase) are in place</td><td rowspan="2">'After the fact' communication to correct the misperception</td><td>Two unrelated designs are still in place (no change in structure affecting rule set)</td></tr>
<tr><td>M</td><td>Price increase is reflected in the system</td><td>Price increase is still reflected in the system (no change in structure affecting system behaviour)</td></tr>
</table>

H	Users take exception to an unexpected increase		Better understanding of the reasons of the two unrelated changes

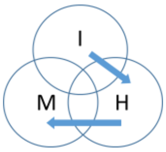
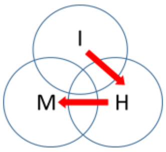
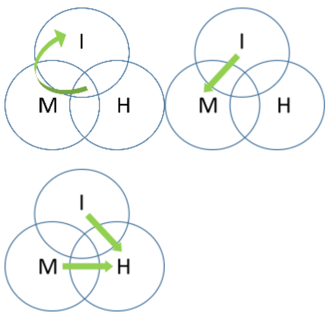
6.4.1.8 UC: Users unfairly pay too little or too much for parking

SBF View		
Design	**Realized Behaviour**	**Design Change**
		
Current zoning plan determines split of spaces between zones	Plan no longer fits this split since individual's practices shifted	City plans to update the current zoning plan with the expectation that it changes human perception and usage of technology
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Existing parking zone plan is obsolete and no longer fits current parking practices	Mismatches between price and parking volume due to dynamic zone pricing	Trust Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Current parking zone plan	Update the current plan	New plan is better aligned with actual parking practices and parking volume

M	Parking spaces are allocated based on the current plan		Parking space re-allocation to take place based on the updated plan
H	Scepticism that the current system is 'fit for purpose'		Re-establishment of trust in the system

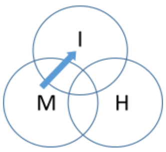
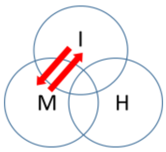
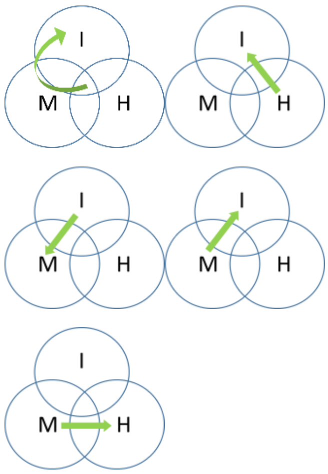
6.4.1.9 UC: Service provider's proposals are unrealistic

SBF View		
Design	**Realized Behaviour**	**Design Change**
		
Platform design (I) fosters creativity across providers (H) for innovation (M)	Subsidies adversely affect competition in service provider community, which also influences innovation	Improved governance process widens innovation and ultimately changes 'attitude' towards the process
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
European Union provides government subsidies to innovators	Skewed innovation towards subsidies instead of true innovation	Substandard innovation, frustration among service providers → Trust Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**

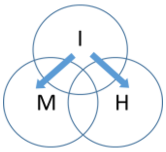
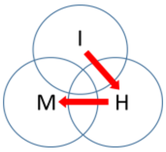
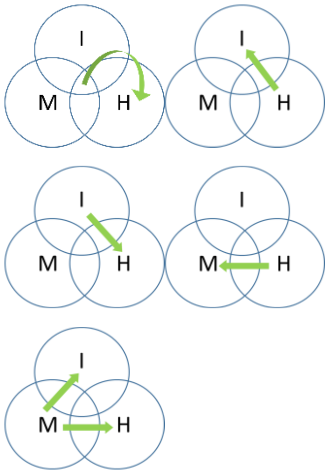
I	Subsidies available for specific types of innovation		Improved governance process to widen topics of innovation
M	N/A	Change in governance process	N/A
H	Competing for subsidies rather than best technological solution		More innovation and increased trust between stakeholders

6.4.1.10 UC: Unscheduled roadwork decreases profit

SBF View		
Design	**Realized Behaviour**	**Design Change**
		
Total number of parking spaces drive revenue and profit plan	Rules for road maintenance make parking spaces unavailable	Rule adjustment, improvement of sensor framework, revenue increase, easing of tensions
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Parking spaces need to be available to be rented out	Unavailability of parking spaces due to road maintenance	Profit Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Loosely handled rules for road maintenance, lack of communication	Better definition of rules to consolidate road work and adjust timing (outside of peak parking hours) – bi-weekly planning meetings between city and service provider	Clear rules
M	Unplanned unavailability of parking spaces resulting in profit erosion		More planful road maintenance and more parking space availability
H	N/A		N/A

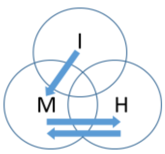
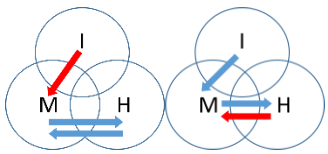
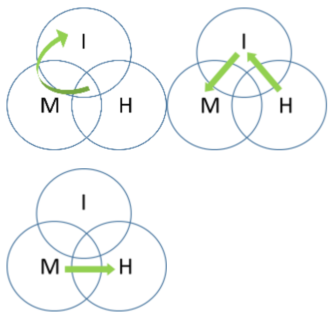
6.4.1.11 UC: Smaller pool of potential service providers

SBF View		
Design	**Realized Behaviour**	**Design Change**
		
Smart City design requires providers to also include technology	Some providers cannot fulfil all requirements due to lack of technical skills	Smart City PMO devised FAQ document and assists providers, skill-level at providers changes, leading to better solutions and improved knowledge base
C-M-O View of Realized Behaviour		

Context +	Mechanism =	Outcome
Smart City requires data from service providers (in addition to service rendered)	Lack of technical knowledge at service provider preventing competition	Profit Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Rule requires technical know-how	Authoring of better documentation with FAQ document and 'hands-on' assistance from the Smart City PMO	No Change
M	Service provision requires addition of IT solution		No Change
H	Lack of IT knowledge disqualifies companies from providing solutions		Increase in technical sophistication allows more companies to compete

6.4.1.12 UC: User frustrated by fine

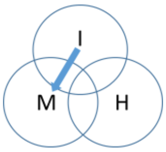
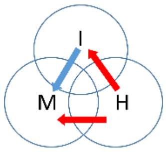
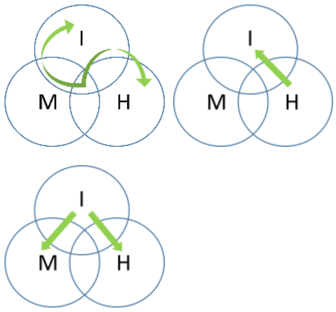
SBF View		
Design	**Realized Behaviour**	**Design Change**
		
The design controlled the interaction between the system and the user	The problem relates back to a substandard hardware and software design	The design was changed to include an additional verification step, design and functionality changed, leading to decreased frustration

SBF View		
Design	**Realized Behaviour**	**Design Change**
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Telpark application and the street parking terminals require accurate data entry	Wrong data entry by user triggering an unexpected fine	User is frustrated by the fine → Trust Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Design required input of data without any validations	Design was modified to prompt user whether the entered data is correct	Additional verification step vastly reduces error rate
M	System accepted any data input	System was changed based on design modification	System now prompts for additional verification step
H	Users were frustrated when receiving unexpected and ‘unfair’ fine	User is forced to comply with the modified design	User frustration has diminished, which is conducive to general system acceptance

6.4.1.13 UC: User outruns scanning vehicle to avoid fine

SBF View		
Design	**Realized Behaviour**	**Design Change**

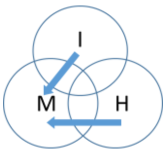
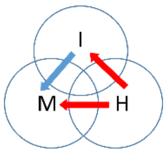
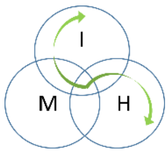
		
Design instructs the scanning vehicle to scan for wrongly parked cars	People's behaviour to outrun vehicle created new general habit	Campaign for the public and vehicle operator training – creation and delivery of the program; and the positive effect on scanning vehicle (near) accidents

C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Service provider uses conspicuous vehicles to determine parking violations	Pre-emptive (unsafe) people actions prior to scanning vehicle arrival	Safety Issue

Time-Phased Morphogenetic View – first cycle for education of public			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Informal norm to 'outrun' scanning vehicle	Warning messages in app and educational mailings	Increased carefulness of users regarding approach of scanning vehicles
M	Accidents took place between pedestrians and motorists	Behavioural change reduces accidents	Reduced number of accidents
H	Users engaged in unsafe behaviour	Warning from application	Less unsafe user behaviour, i.e., not crossing in front of vehicle

Time-Phased Morphogenetic View – second cycle for vehicle operator training			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Increased carefulness	Training provided to scanning vehicle operators	Vehicle operators are sensitized to the problem and operate carefully
M	Reduced number of accidents	Scanning vehicles are in fewer accidents	Further reduced number of accidents
H	Less unsafe user behaviour	Scanning vehicles slow down	Users get in even fewer unsafe situations

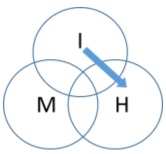
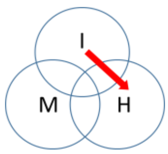
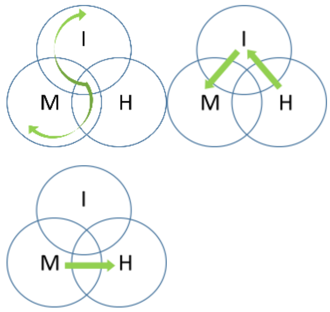
6.4.1.14 UC: Drop in scanning vehicle efficiency

SBF View		
Design	**Realized Behaviour**	**Design Change**
		
Original design had all routes covered by scanning vehicles	Collective human action diminishes efficiency of scanning vehicle and creates informal (new) rule	City changed rule to have busy streets serviced by humans and not vehicles
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Humans possess more agility in crowded spaces than inflexible vehicles	Excessive traffic volume causing inefficiency of scanning vehicles	Efficiency Decrease → Profit Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**

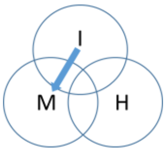
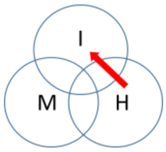
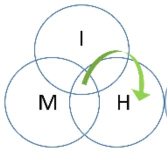
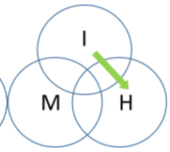
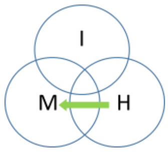
I	Design calls for all streets to be serviced by scanning vehicles	Replace scanning vehicles with human patrollers when traffic volume renders scanning vehicles less efficient	New design to differentiate based on traffic volume is implemented
M	Scanning vehicles operate 'as is' regardless of their efficiency factor		Approx. 80% of streets are serviced by scanning vehicles, 20% by human patrollers
H	Human enforcers are not utilized		Human patrollers can harvest efficiency gains where scanning vehicles are unable to do so

6.4.1.15 UC: Two-hour parking maximum alters behaviour

SBF View		
Design	**Realized Behaviour**	**Design Change**
		
Design enforces max. parking time of two hours on user during peak times	Users relocate their cars to comply with the rule to stay over two hours in the area	POTENTIAL—tie rule (I) to parking volume, suspend if there are enough spaces
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
System restricts parking during peak times to enable more people to park	Disruption due to car relocations (post two-hour limit in peak times)	Frustration with the system → Trust Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Two-hour rule is in force during peak times	Modify rule to suspend enforcement when number of parked cars is low	Two-hour rule is suspended (in peak times) if traffic volume permits
M	N/A		N/A
H	Users are relocating cars		Users do not have to relocate cars if there is no competition for spaces

6.4.1.16 UC: Delayed compliance checks conducive to rule breaking

SBF View		
Design	**Realized Behaviour**	**Design Change**
		  
System designed for scanning vehicles to patrol 80% of routes	Low scanning frequency prompts some users to take the risk of not paying	Appeal to people’s sense of fairness, change user’s individual attitudes and affect change on the system
C-M-O View of Realized Behaviour		
Context +	**Mechanism =**	**Outcome**
Controls validate that people paid for parking	Increases of non-payment due to decreased patrol frequency	Profit Erosion

Time-Phased Morphogenetic View			
Circle	**Pre-existing Structure**	**Action**	**Structural Elaboration**
I	Design is set where scanning vehicles patrol most routes	Educational campaign that appeals to people's 'sense of fairness'	No Change
M	80% of routes are served by vehicles		No Change
H	Higher occurrence of parking without paying		Lower occurrence of parking without paying

6.4.2 Application of the SBF on Santander's UCs

This part of the chapter overlays the SBF onto the UCs that were identified in the Santander case study. It is an exploration into the question of how a systematic application of the framework could have helped to avoid the experienced negative UCs. It does this by systematically stepping through each arrow of the framework and examining the interplay between the two circles that are connected through the arrow. This interplay relates to events in the operational (process-related) or strategic use of the system that was not planned for. The framework is therefore a vehicle to proactively think through design and implementation questions as early in the process as possible. Ideally, this would occur in the design stage prior to implementation and user testing taking place. When design and implementation considerations are addressed in the conceptualization or design phases, adjustments can be made more easily – this will then hopefully increase the probability for a successful system implementation.

6.4.2.1 Arrow 1 – Human Agency (H) influencing Interpretive Schema (I)

This is an occurrence where personal routines, habits, dispositions, and opinions have the potential to form new, or alter existing, norms, rules, laws, designs, and standards. It is the conglomerate of actions, occurring individually and channelled collectively, that has the potential of affecting change in the wider-ranging rule sets of society.

One potential start in exploring the interaction between Human Agency and Interpretive Schema would be occurrences where users have attempted to get around rules, laws, or a system's design. In the Santander case, there is one prevalent example where the action of individual users has established a collective new informal norm: users outrunning the scanning vehicle to avoid fines (see Section 6.2.22 for detailed findings). Here, one action to alleviate the problem from the start could have been safety training for scanning vehicle operators, which in Santander, was implemented much later. A fuller set of 'readymade' counteractions could be developed with a focus group that tries to identify all scenarios where users would aim to get an advantage over the system, meaning wherever somebody might want to 'outsmart' a rule.

The next step in illuminating the interaction between the two circles could be an examination where altering the rule set would decrease negative effects of UCs. For example, there have been cases where users are frustrated by fines (see Section 6.2.20 and 6.2.21), while technically justified, these fines were considered 'unfair' since the user made a relatively simple data entry mistake. One possible modification to the rule here could be a 'one time forgiveness' where the system allows for one parking infraction to be forgiven without a fine. Another option could be a warning instead of a fine. These would have counteracted the resulting frustrations by users and therefore the ensuing erosion of trust.

Early involvement of users is key in designing solutions that fit the user's requirements but also allow for better acceptance by the user community. One UC found was that user non-involvement from the start fostered resentment (see Section 6.2.1). The acceptance level was ultimately increased, but if the city had instituted focus groups before implementation, and had taken their input into account, the initial trust erosion could likely have been avoided.

These examples are remedial in nature in the sense of 'what would have changed if the Santander team had done something else proactively instead?' The framework suggests looking anticipatorily into possible Human Agency implications (circle H) that may ultimately alter the collective rule set (circle I). In a more standardized fashion, this could be accomplished by taking every use case of a new technology application and asking the question whether the existing interpretive schema optimally support the user's experience. If this is not the case, the project team should foresee to proactively harmonize the rule(s).

6.4.2.2 Arrow 2 – Interpretive Schema (I) influencing Human Agency (H)

Many effects of trust erosion in the system stem from two overarching problems: the system design not adequately reflecting the needs and requirements of the user community, and the design, rules, etc. not being adequately understood and accepted by the user community.

Santander experienced significant resistance from residents against the newly implemented system. The project team, like with many technology development initiatives, did not sufficiently <u>involve the user community from the beginning</u> in the definition and design of the solution. The system was subsequently met with resistance by the user community, which was a turn that the project team did initially not comprehend. User acceptance is never guaranteed, but the conditions can be set for the likelihood of acceptance to increase. This basic condition for success starts with fully involving users from the beginning (McKeen and Guimaraes, 1997: 133-134).

There are similar trust erosion issues when underlying <u>rules are not understood or accepted</u> by users. The routines of citizens were disrupted when the city installed sensors under the road surface. The side effects of this road construction (traffic blockage, no parking, noise, etc.) resulted in a significant change management issue going back to a lack of context and understanding of what the change entailed. The installation of sensors in the streets proved to be much more disruptive than originally anticipated by the project team. There was no upfront communication as to what residents who live and work on the affected streets were to expect. This disruption was coupled with people not having answers to questions such as ‘why is this taking place?’ and ‘how long will the road be unusable?’. It caused an angry reaction of people who live and work alongside the affected streets.

The residents of Santander did not understand that two unrelated events taking place simultaneously were in reality not related: the increase of parking fees across the city and the introduction of the new parking system. The two actions were unrelated, but the fee increase negatively affected the perception, and therefore the acceptance, of the parking system. Again, this could be traced back to a lack of communication from the project team that resulted in this misunderstanding.

<u>Outdated rules</u> can also cause issues with trust in a new system. This occurred with the rule that determines the split between resident and visitor parking spaces (see Section 6.2.3). Santander experiences a drastic seasonal increase of visitors in the summer that causes parking shortages experienced by residents. The city has for a long time determined this split between residents and visitor parking spaces on an annual basis. The division between resident and visitor parking requirements is different between the summer and winter months in Santander. Consequently, the delineation between these groups of parking customers should be set on a quarterly basis.

Another example of outdated rules leading to trust erosion is the current division of streets into parking zones. The rule of which streets belong to which parking zone, for dynamic pricing, is obsolete and has hampered the success of the parking system. Two additional rules and standards that did not fit the modern solution was an outdated governance process between the city, project team, and solution providers, and financial incentives that prompted for the wrong behaviour of solution providers.

Perhaps the best example of an outdated rule is Spain's strict data privacy law that has hindered the implementation of parking cameras in lieu of sensors. Over the past ten years, the ability for cameras to recognize parked cars and their associated license plates has increased significantly. In addition, there are several fundamental technical issues with sensors that the technical community has been unable to overcome. These are a lack of sensor reading accuracy, difficulty of placement by having to burrow the sensor into the road, difficulty of replacing sensors (for battery exchange or repair), high cost to purchase and install, and sensitivity to water damage, pressure, etc. Cities in Spain are constrained in upgrading their parking technology from sensors to cameras, which is a limitation that does not exist in other countries.

The last category of Interpretive Schema influencing Human Agency is with existing rules that are basically valuable, but that require small adjustments to make them work better. One example is the requirement in Santander for parking users to move their car every two hours during peak times if they want to remain in the area. While this rule makes sense if there is a shortage of parking spaces, it does not make sense that a person is required to retrieve the car, drive it to the next street, and pay for an additional two hours of parking. Also, the fact that automated parking validation vehicles are used more commonly than street patrol officers has caused an unintended side effect. The lack of the authoritative presence of a patrol officer encourages some people to overstay their parking times. The solution to this problem would be the increase in frequency of scanning vehicles and/or the addition of more human patrol officers.

In summary, the *state* of a rule can be tied to suggested remedial actions that all affect this pathway of the framework as described in Table 6.2:

Table 6.2 – Mapping of rule existence to state to suggested remedial action

Rule exists?	**State**	**Suggested remedial action**
No	Needs to be created	Involve users through surveys, focus groups, interviews, etc.
Yes	Outdated	Revise rule by observing actions of resistance against the rule, utilize focus groups
Yes	Not understood	Provide education to users

Table 6.2 – Mapping of rule existence to state to suggested remedial action		
Rule exists?	**State**	**Suggested remedial action**
Yes	Understood but not accepted	Understand reasons for non-acceptance – modify rule or educate people regarding reason for the rule
Yes	Understood and accepted, but requires tweaks	Observe existing issue with the rule and modify accordingly

6.4.2.3 Arrow 3 – Human Agency (H) influencing Material Agency (M)

In this pathway, people's dispositions and personal routines influence the functioning of the system. In the encountered findings in Santander, this interaction occurred in a negative connotation. Here, people either accidentally or deliberately interfered with the system.

In the example where people attempt to outrun an approaching scanning vehicle to avoid a fine, the interference with the machine poses a danger to the person and others. It is what Orlikowski (2000: 409) referred to as intentional unfaithful usage. The city and service provider responded first with the inclusion of messages on the Smart Santander phone application and by adding leaflets to mailings. In a second step, the service provider trained scanning vehicle operators to watch for this behaviour.

Another rather extreme example is sabotage where people have deliberately destroyed sensors out of frustration. The same issue (frustration, no ownership during conceptualization and planning) also expressed itself when users actively resist the system. In reference to Orlikowski (2000: 409), this relates to a misperception and/or lack of understanding of the system.

One finding that is not a deliberate impediment to this pathway is the faithful yet inefficient execution of a process (DeSanctis and Poole, 1994: 129-130). This is where the general 'busyness' of a street negatively influences the efficiency of automated scanning vehicles. Here, the efficiency measurement of scanning vehicles resembles a parabola where the y-axis reflects efficiency, and the x-axis expresses traffic volume. Scanning vehicles are faster and more accurate than human patrol officers – up to a point where manoeuvring through a crowded space cedes the advantage to a nimbler human patrol officer.

The specific questions that the design team could be asking as to 'how' users are employing the system's functionality for their benefit are as follows:

Is the material agency appropriated faithfully by the users (as expected)?

If not, meaning that the usage of the system occurs in an unfaithful or unexpected fashion, as per the DeSanctis and Poole definition, what are the reasons?

Is this due to an error such as misperception, lack of understanding of the system, or an accidental slippage or other error?

Is this due to an intentional unfaithful usage of the system such as is the case with sabotage, or inertia?

6.4.2.4 Arrow 4 – Material Agency (M) influencing Human Agency (H)

In this interaction, the system's affordances (or constraints) affect abilities, skills, disposition, or personal routines of humans.

Most of the eight findings attributed to this pathway relate back to the fact that sensor-based systems are technologically challenging and error prone. Sensors are buried in the asphalt and maintenance is therefore elaborate and expensive since every access to the sensor, for battery replacement, etc., requires breaking open the street cover. As a side effect, sensor replacement or repair is often delayed. Until such time as the sensor is working again, the space occupancy signal for the affected parking space is unusable, which causes an erosion of trust in the system. Sensors also require the exact placement of objects above them to register the signal, which has proven to be problematic when it comes to motorcycles or the general inexact parking of vehicles. In addition, sensors have been identified as a tripping hazard in case they get exposed on the road.

The lack of maintenance has also created issues with other technical installations in Santander: Street panels that display the number of available parking spaces and broken street payment terminals that do not allow a user to pay for parking. Collectively, the lack of functioning technology contributed to the erosion of trust in the system.

One unintended consequence is the mere presence of technology in lieu of a human parking attendant. The anonymity of the system has contributed to some users not paying for parking, which caused profit erosion on the side of the parking service provider.

The findings suggest that three overarching questions ought to be answered when implementing a technology solution:

1. Is the technology fit for purpose?

    Is it expected to be viable in the long term?

Have other cities had experiences (positive or negative) with the technology variants that are being considered?

Is it scalable in the long run?

2. Can the technology choice be financially supported for its full life expectancy?

   The number of malfunctioning sensors, street display panels, and parking payment terminals in Santander suggest that the city at times has difficulties with the ongoing upkeep of the system. Every sensor, or other equipment that does not work, has the potential to erode the user's trust in the system.

3. How would humans react in the presence of a particular technology?

   This is where true UCs could be derived. In the early stage of a Smart City project, this could be accomplished through focus groups that perform a 'dry run' or walk-through of the envisioned solution. Once equipment for a prototype has been secured, the same user group could simulate daily interaction with the technology. Another option is to reach out to other Smart Cities that have implemented the same technology.

4. What does the technology not do that might have a consequence for the system?

   This is consistent with the principles of CR that accounts for effects due to non-action.

6.4.2.5 Arrow 5 – Interpretive Schema (I) influencing Material Agency (M)

Based on the data analysed, this interaction can take place on two different planes:

At a macro (strategy) level, plans and rules, etc., influence the system at large. The lack of coordinated planning between the city and the service provider affected the uptime of sensors and therefore negatively influenced profit.

At a lower (micro) or process-related level, the findings all pointed to the system's design that was enabled or constrained by how the system behaved. At the detailed level, the system's design did not contain validation steps to make sure that the user entered data correctly. Several of the design's implications onto the Material Agency's affordances and constraints were also at odds with the human's ability, different actions, or needs. Examples are that the user cannot select a parking spot while driving and that physical spaces were no longer available upon the driver's arrival at the location.

In addition to the actions already taken, another improvement would be for the system not having to depend on the user entering a license plate in the first place. This could be accomplished through installed cameras, which is technically feasible.

The SBF could have been used in this case to also think through the interactions between Human Agency (H) and Material Agency (M). The Interpretive Schema (I) in this context acts as a 'mediator' between the human and the machine. If we expect humans making mistakes, the design should better anticipate where these mistakes could occur and prepare the system (M) to foresee these issues in the process flow.

6.4.2.6 Arrow 6 – Material Agency (M) influencing Interpretive Schema (I)

While much of a system's design should be informed by the user's needs and desires, the second important design influencer are affordances and constraints that the technical solution provides. This is often referred to as the 'art of the possible' where technology options open new perspectives into user's needs. In this case, the creative brainstorming process of how technical possibilities drive certain design features is paramount. One prime example in this context is Apple and the smartphone industry in general. The technical sophistication of the user interface, to a large extent, drove people's requirements. This occurred, for example, through touch-screen technology, voice activated commands, or the ability for companies to create their own apps and include them in an apps store. These three technical possibilities set requirements to draw patterns, talk to our smartphones, and potentially download applications that we did not think we needed.

Santander exhibited several constraints from the Material Agency circle into the design. For example, the 'forced choice' due to local privacy limitations, of sensors instead of cameras influenced the design of the system. In addition, from a financial perspective, the cost of the chosen technology exceeded the financial plan, in this case the rule set that guided the budget.

6.4.2.7 Arrow 7, 8, 9 – Formation of new routines, technology, norms, rules, laws, designs, standards

Arrows 7 through 9 behave differently in that they reflect actions rather than potential operational or strategic issues that could be the result of the interplay between arrows 1 through 6. Arrows 7 through 9 reflect, in a sociomaterial sense, what Santander has done to address shortcomings, and in some cases, what a city could do to rectify issues.

The largest undertaking for Santander will be to upgrade the outdated sensor-based technology with a camera-based system. The first step that the city is currently engaged in is the construction of a business case that will hopefully provide the basis for the subsequent upgrade to the solution. It is important that users are involved very early in the design of the new solution. This could be via focus groups, questionnaires, direct interviews in the streets, etc.

For companies that will provide new solutions, governance surrounding procurement activities will have to be adjusted to enable a fair competition. Also, there are service providers whose core expertise is not with technology and the Program Management Office has undertaken actions to aid these service providers in navigating the requirements and build-out of technology.

Santander has adjusted and refined its planning processes. For example, financial plans now contain more realistic assumptions and are deemed more accurate. Human patrollers, in lieu of automated scanning vehicles, were reinstated in some streets where it makes sense due to high traffic volume. There is now better coordination across the departments that deal with street work and maintenance. The city is in the process of revising their resident pass allocation process to not artificially constrain the number of available resident parking spaces. It is also considering a re-mapping of streets into appropriate parking zones that are used for dynamic pricing.

From a more detailed system design perspective, the city and service provider have included additional validation steps in the Smart Santander and parking payment terminal applications to help avoid user data entry errors. Adjustments to the two-hour parking rule, provided that there are enough spaces available, are also being considered.

Perhaps the most important area for improvement is that the city and service provider have spent considerable resources on change/management initiatives and educational campaigns. These explain the goals and scope of the Smart Santander parking program more clearly and appeal at people’s sense of fairness to pay for what should be paid for. The campaigns addressed the ‘free rider syndrome’ and helped with people’s unsafe behaviour around vehicles. The additional information provided by Santander’s Smart City Program Management Office has set a new level of ownership across residents.

The next chapter elaborates on these findings with regards to theory while reviewing the findings in the context of the literature review and salient parts of the research methodology chapter.

7 Discussion

"And this is where the central challenge lies: moving from a shapeless data spaghetti toward some kind of theoretical understanding that does not betray the richness, dynamism, and complexity of the data but that is understandable and potentially useful to others." (Langley, 1999: 694)

7.1 Introduction to discussion

"Let us make sense whatever way we can." (Langley, 1999: 708)

The Santander case study represents a typical Intelligent Parking Assistant (IPA) system as identified by Giuffrè *et al.* (2012: 17-19) and as described in Section 1.5. The parking solution consists of street parking spaces with connected (networked) sensors to track space availability and with payment being handled through mobile devices. The system thus possesses high technical complexity with frequently occurring interactions between 100+ parking sensors, users, and the system for setting up a user profile, selecting a parking space via the app or street display panels, space selection as per the map of available spaces, parking activation, time expiration reminders, extensions, etc. Based on these characteristics, there is an almost complete overlap with the descriptions of Giuffrè *et al.* and what was found *in vivo* in Santander.

The interactions between users and the technology were designed to occur in an interactive fashion, which confirms that looking at this case solely through the lenses of *technological determinism* or *social determinism* is insufficient. Both forms argue that there is a starting point that results in the exertion of influence on the complementing side. With technological determinism, technology elicits a social response, and with social determinism, human activities guide the system's activities.

In the case of Santander, the 'human activity' of parking in a spot only prompts for a predictable systematic response if several conditions are true – for example that the car is parked exactly over the sensor and that it has sufficient metal density for the sensor to recognize it as a car. If this is not the case, the system does not respond. Conversely, the technology of a street parking panel shows the available spaces within a street and an area, but it does this only in a reliable fashion if the incoming sensor data is accurate. If too many users park their cars in an imprecise fashion, where the spot is occupied but the sensors do not register the action, the street display panel will show incorrect data, likely prompting drivers to make decisions that otherwise they would not make. This 'Catch-22' situation presents a mutually dependent dilemma and shows the inadequacy of using technological or social determinism on their own.

Users who park the car (incorrectly, in this example) and who take guidance from the system's incorrect information (whether or not to park in a particular area, street, or parking spot) *create* the very condition that *leads* them to make a flawed decision later. Here, humans and technology are in a reciprocal, temporally emergent, dialectic of resistance and accommodation (Pickering, 1993: 567, 576), which Cecez-Kecmanovic *et al.* define as an *intra-active co-constitution* of Human as well as Material Agency. (2014: 809). The consequences of this extend to collective Interpretive Schemas that then in-turn influence the co-constituted Human and Material Agency.

This means that *technical determinism* or *social determinism* by itself could not be applied since there is no distinct 'hand-over point' between one side to the other. In a paradigmatic extension, Positivism would be ineffective when applied to this problem: While binary 'car/no car' measurements are real, such a reality would be difficult to apprehend by people who park their cars and who expect for parking spaces to be available when in fact they are not (Niemimaa, 2016: 48). From an onto-epistemological standpoint, the problem points us to Critical Realism (CR) where we *accept the reality* of flawed parking availability signals, but such a reality is *imperfectly apprehensible*. What follows is a step-by-step answer to all four research sub-questions with the help of CR.

The first answer is provided for research sub-question 2 since it best allows a complete end-to-end walkthrough of the CR approach coupled with Analytical Dualism directed towards a sociomaterial entanglement:

7.2 Research sub-question 2: What are the potential generative mechanisms behind unintended consequences and how can we model them?

"For a generative mechanism is nothing other than a way of acting of a thing." (Archer et al., 2013: 38)

The answer to this demonstrates the usage of the SBF by highlighting how the individual pathways (arrows) of the framework build upon each other over time-phased instantiations. This is shown with two examples of an unintended consequence (UC).

7.2.1 Theoretical expansion of one exemplar unintended consequence: Expected parking space unavailable

The UC of finding an expected parking space being unavailable upon arrival has resulted in the erosion of trust in the system. If too many users park their cars in an imprecise fashion, where the spot is occupied but the sensors do not register the action, the street display panel will show incorrect data, likely prompting drivers to make decisions that otherwise they would not make.

In delving deeper into this UC, we see that the data reveals <u>eight</u> findings that all relate to this one UC. These findings are due to quality and design limitations within the system as well as due to drivers avoiding using the system. In addition to the example brought forward in the previous section, i.e., users not parking precisely on sensors (a <u>human agency</u> problem), we know that the employed magnetics sensor technology in Santander is technologically inferior to other technologies such as camera usage. This points to an issue that applies to the <u>material agency</u> of the solution. Many Smart Cities across the globe employ cameras instead of magnetic sensors resulting in much more accurate parking spot availability data. However, Spanish data privacy laws, considered an <u>interpretive schema</u>, did not permit the installation of cameras when the Smart Santander project commenced. Another problem affecting <u>material agency</u> is the fact that motorcycles can occupy an entire parking space, which is then unavailable to other drivers, but where the motorcycle's presence may not be registered since they are smaller than cars and possess lower metal density that may not activate the sensor.

In moving beyond the applicability question of technical and social determinism, the issue of 'expected available parking spaces that turn out to be unavailable' represents an inseparable combination of the technical and the social that is consistent with the sociomaterial viewpoint (Orlikowski and Scott, 2008: 434, 454). In this example, we are confronted with an entangled, unpredictable, and unstable union of Human Agency, Material Agency, and Interpretive Schema that resulted in the dissolution of boundaries and complete assimilation between humans, technology, and rules (Orlikowski and Scott, 2008: 434, 454) where all three are constitutively entangled (Scott and Orlikowski, 2014).

Let us return to the previously described 'Catch-22' situation of the mutually dependent dilemma where imprecise car positioning over sensors (with a resulting incorrect availability signal) leads to subsequent flawed parking decisions when taking erroneous availability data into account. This example serves as the basis for describing three fundamental concepts of the thesis: a stratified reality, the combination of ontological realism and epistemological relativism, and Analytical Dualism.

The concept of a **stratified reality** is a cornerstone of Critical Realism (CR) in that reality is distinguished between the *empirical*, *actual*, and *real* domains (see Section 3.1.2.1). There is an *empirical* observation that a parking space showing as available in the Smart Santander application is in fact unavailable when the driver arrives at the spot. We know that this situation, i.e., the observation, is predicated on one of more generative mechanism(s) that was (were) activated in the *actual* domain, but we do not know which one(s). Up to this point, there is ontological consistency with other paradigms: Positivism and strict Realism accept the single truth of parking space unavailability and the related issue of sensor precision. Nominalism may not accept the reality of the situation, but the nominalist still experiences the same outcome: no parking space when it was anticipated and sensors that provide incorrect occupancy signals. In this, we see CR's ability to subsume positivist, interpretive, and critical world views (Niemimaa, 2016: 48).

Where CR distinguishes itself from other paradigms is when we reach the *intransitive* dimension and the domain of the *real*. Here, we turn towards **ontological realism and epistemological relativism** (Reed, 2011: 8), which Bhaskar saw as entirely compatible and in mutual entailment (Bhaskar, 2013b: 34). We use this epistemological stance as a tool to gain insights into the *real*. While our *empirical* observation of unavailable parking spaces is true, we do not know what generative mechanisms (causal powers) produced this effect. So, in fully accepting Sociomateriality's *constitutive entanglement*, we now probe deeper into the unobservable mechanisms that would cause for the parking space not to be available.

The observation that "imprecise car positioning leads to subsequent flawed decisions" provides an entry point to the Sociomaterial entanglement form. Nicod's criterion reminds us that flawed decisions can result from much more than the one condition of "imprecise car positioning", which presents us with multi-causality or in 'CR terms' equifinality (Bhaskar, 2008: 133). The operative adjective in our observation is "subsequent", which hints at the dimension of *time*. Langley *et al.* remind us of the importance of temporality and flow in dynamic processes (2013: 4), Faulkner and Runde underline the endurance of events that can occur over time (2010: 3), Morell emphasizes the value of time when considering unintended consequences (2018: 243), and Volkoff and Strong state that *"actualization of affordances occurs over time"* (2013: 824).

The dimension of *time* is the essential key that allows us to examine the individual components of the *constitutively entangled* by holding the social and the material apart in their interplay (Mutch, 2013: 29). Margaret Archer's **Analytical Dualism** is the tool that allows us to analytically penetrate the sociotechnical 'monolith' via time-based slices and arranging these temporal slivers into prior structures, actions, and resulting new structures (2010: 228, 238). For one (analytical) moment in time, the focus shifts as contours begin to appear and entanglements become imbrications (Ciborra, 2006) that can be unlocked, disconnected, separated, and examined (Kautz and Jensen, 2012: 5). We will now further explore this exemplar unintended consequence by stepping through each time-phased slice:

7.2.1.1 Time-phased instantiation # 1

For this, we go back to the year 2010 before the system was designed. In this time slice, we do not have relevant observations of Human Agency or Material Agency in the *empirical* domain since the system did not yet exist. We do have a present structure, an imbrication, of an Interpretive Schema: Spain's existing data privacy law. CR guides us towards the explication of structure and context; in this case it is the condition that the law did not allow the installation of cameras in public places. With this, we have a structure (law), an action (non-installation of cameras, or in other words, the installation of sensors), and the contextual condition for this setting (Wynn Jr and Williams, 2012: 789, 798; Sayer, 1992: 95). At this point, we can abductively reason that there is an incongruency between Material Agency (camera) and the Interpretive Schema (law) as expressed through pathway (arrow) 6 in the Sociotechnical Behavioural Framework (SBF). Simultaneously, we know from interviews that citizen's attitudes towards cameras are highly sceptical as expressed by Informant O1: *"we also don't like to give up privacy."* This affects arrow 1 (Human Agency influencing Interpretive Schema) of the SBF.

We now know that arrows 1 and 6 of the SBF are implicated and thus we have started to build a bridge from CR's *empirical* to the *real* domain. However, we do not know the order without performing a retroduction to help us crystallize the sequence. Here, we work backwards from the structural configuration to the underlying generative mechanism (Reed, 2011: 5) and along the pathways of the SBF: Would there be an 'anti-camera law' (Interpretive Schema) if people's attitudes (Human Agency) were 'pro camera'? = unlikely; would there be cameras (Material Agency) if the law did not exist = likely. We can therefore assume that **arrow 1 was likely activated before arrow 6**. The sequential order of the two arrows is endorsed by an empirical corroboration of convincing depth regarding causality (Wynn Jr and Williams, 2012: 801): It is highly plausible that societal opinions result in new legislation that then results in the application of the new law in 'real life' – in our case in the restriction of cameras and thus the installation of sensors.

The structural elaboration that then followed was the installation of sensors instead of cameras.

7.2.1.2 Time-phased instantiation # 2

Once the sensors were implemented, around 2012, the issue of inexact positioning of cars above sensors started to occur. We know that conditions had to be 'near perfect' for the sensor to correctly record a car's presence. We can abductively reason that Material Agency (the sensor's lack of precision) influenced Human Agency (**arrow 4**) in that there developed a trust issue in the accurate reporting of available parking spaces: *"When [the system] works, then* *there is no problem, but I have given up looking up parking info. I come and if there is a space, then it's OK."* (Informant R2) and *"Sometimes, the screen [application] tells you that spaces are available, but when you get to them, they are not available."* (Informant R1).

The retroductive question then becomes "if the system worked in 100% of the cases, would people mistrust the system?" – the answer is likely not.

There is a related finding (see Section 6.2.19) that describes the sensor's inability to pick up the presence of a motorcycle if it is not parked exactly above the sensor or if it does not contain the required metal density. We can abductively assume that the comments of Informant R9 substantiate the lack of trust in the system: "*I don't have a car, but a motor bike and it doesn't really work well. It's set up for automobiles, but not for motorbikes. When I park my bike in a spot, it will still be available on the app. I can pay and enter the license plate, etc. But it says that the space is available when it is not.*" The answer to the retroductive question remains the same: it is unlikely for users to mistrust the system if it correctly recognized each occupied parking spot.

7.2.1.3 Time-phased instantiation # 3

As the Santander parking system usage increased, after 2012, it raised two issues that were exacerbated with the increased utilization of the system: the fact that parking spot selection is impossible while driving (see Section 6.2.14) and free parking spaces that are visible on the Smart Santander app may no longer be available upon arrival (see Section 6.2.15).

The researcher observed *empirically* by using the Smart Santander application, that it is virtually impossible, and certainly unsafe, to look at the map of available parking spots while driving. If a driver wants to utilize the application to look up available spaces, it must be done prior to starting to drive or by parking the car mid-journey to operate the smartphone. The result in either case is the additional time that it takes between identifying an available space and arriving at this space. There is an inverse relationship between the length of time that it takes to arrive at the parking space and the probability for this space to still be available. There is a combination between the design limitation of the system (Interpretive Schema) the affordances of the smartphone in that it cannot (should not) be operated while driving (Material Agency), and the Human Agency that sets limits on a person's ability to multitask. The combination of all three represents a structure in CR, an imbrication or assemblage (DeLanda, 2019) as a *"set of internally related objects or practices"* (Sayer, 1999: 11).

Abductive reasoning reveals that the structure of all three elements has two entry points for a potential change: Interpretive Schema (the design) and Material Agency (the usability of the gadget to look up parking spaces). The third, Human Agency, would be more difficult to change since general human cognitive ability is not easily altered. In looking at the two remaining SBF circles (Interpretive Schema and Material Agency) retroductively, our likely target is **arrow 5** (Interpretive Schema influencing Material Agency) since the design should be able to accommodate technical and human limitations and provide a solution that fits the given situation.

A related issue is the fact that the Smart Santander application does not allow users to reserve parking spots (see Section 6.2.15), which results in the exact same effect that the parking space is no longer available upon arrival. The issue also points to a limitation in the design (Interpretive Schema) within the assemblage of Material and Human Agency.

We can clearly pinpoint **arrow 5** (Interpretive Schema influencing Material Agency) and ask inductively "if the ability to reserve parking spots in the app would increase the likelihood of availability upon arrival"? The answer here is a clear "yes".

7.2.1.4 Time-phased instantiation # 4

Towards 2016/2017, there was an increase in the occurrence of broken sensors that were not replaced by the service provider. Informant R2 lays out the impact of this *empirical* finding on the UC of 'Expected parking space unavailable': *"[the system] does not work very well at all. It's quite often that the app says that a space is available, or that many spaces are available, and in the end, another car is parked there or the whole row is full. There are many sensors that are not functioning or not functioning well. <u>The city doesn't replace sensors if they are broken.</u>"* Informant R2 specifically refers to the trust issue that emerges from the lack of an accurate parking space picture in the application: *"When [the system] works, then there is no problem, but <u>I have given up looking up parking info.</u>"* The attitude of users (Human Agency) is affected by the state of broken sensors (Material Agency) as expressed in **arrow 4**.

7.2.1.5 Time-phased instantiation # 5

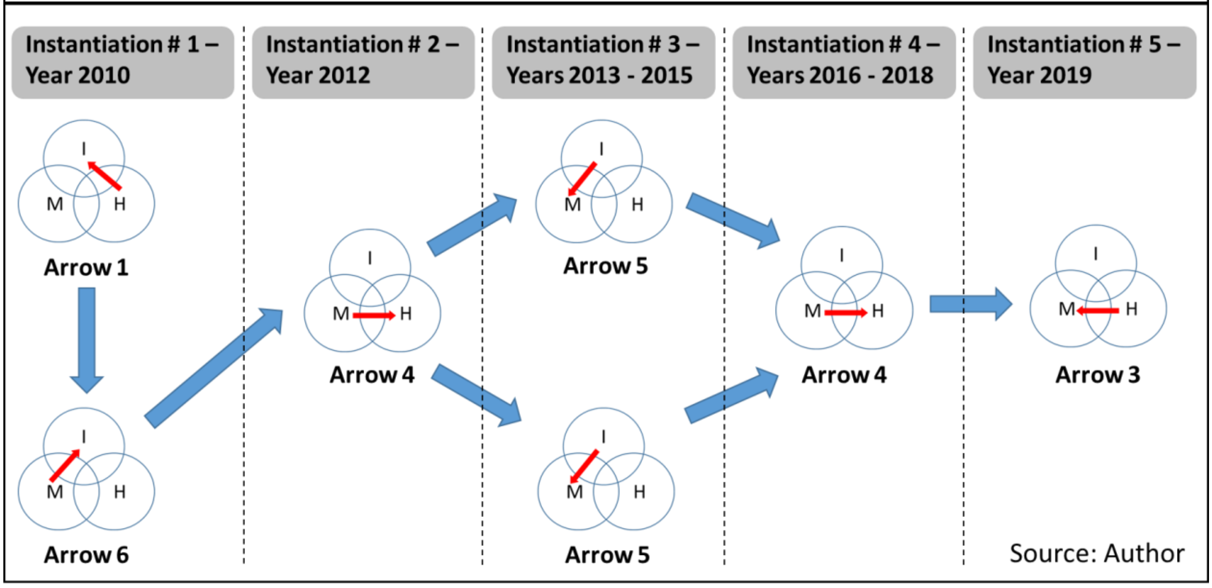
More recently, at the time of the interviews in Santander in 2019, there were occurrences of vandalism where people deliberately destroyed sensors. This aggravated the predictability problem of parking spaces since fewer functioning sensors further distort the availability picture. Why do people wilfully damage these instruments? We will not be able to answer this question in the absence of asking the perpetrators regarding their motives. What we do know for certain is that Human Agency (in this case the attitude of certain people) has a direct effect on Material Agency through the route of **arrow 3**.

Here, we could propose an inductive argument that spans across all previous instantiations of the problem: fewer functioning sensors = reduced trust in the system.

7.2.1.6 Temporal flow of time-phased instantiations

The previously described five time-phased instantiations can be summarized in a timeline laid out in Figure 7.1:

Figure 7.1 – Time-Phased Instantiation of UC 'Expected parking space unavailable'



The analysis suggests that Santander could undertake a set of actions to counter the trust erosion in the system. Since we can trace time-phased causal suggestions through the framework, we can also suggest the priority order for these actions:

1. Attempt to affect legislative change by presenting convincing arguments that cameras used for parking monitoring pose little data privacy risk. These cameras are fundamentally different from surveillance equipment that use facial recognition to track movements of people.
2. Find a solution to the sensor calibration issue where cars or motorcycles are not detected. One option would be investing in higher quality sensors that are more sensitive to metal density recognition. Another solution could be the installation of two sensors per parking spot to increase the likelihood of a positive reading if the spot is occupied (as long as one of the two sensors detects an object, the space would be marked as 'occupied').
3. Invest in a more sophisticated user interface that allows for 'hands free' selection of a parking space while driving. One possibility would be connecting the application to the car's entertainment system where the parking map is displayed on the screen. Another method is using a voice-recognition interface to allow the user to interactively talk to the application.

4. Change the fundamental design of the system from currently only allowing the viewing of free parking spaces to having a reservation function that holds a parking space for a certain amount of time or until the driver arrives at the spot.
5. Swiftly repair broken sensors.
6. Appeal to the public to protect public property (for example via signs) to counter the occurrence of people intentionally destroying sensors.

7.2.1.7 Theoretical expansion of a second exemplar unintended consequence: Two-hour parking maximum alters behaviour

This UC results from the system's design where the maximum parking duration is limited to 120 minutes (two hours) during peak parking times (weekdays between 10am to 2pm and 4pm to 8pm, Saturdays between 10am to 2pm). The enforced two-hour limit causes people to frequently repark their cars, if they desire to stay longer, since the selection of a new parking spot resets the timer. This in turn leads to a disruption in the user's personal routine (see details in Section 6.2.24).

From the vantage point of Sociomateriality, we see the entanglement between the designer's intention to systematically enforce a two-hour parking time limit, the user's desire to stay longer, the user's subsequent workaround to repark the car before the two-hour mark expires, the disruption that this action brings to the person's routine, the attitude change of the user, and the potential attitude change of people who are in the presence of the user while s/he leaves to move the car.

From the viewpoint of CR, we recognize the *empirical* and the *actual* domains both point us ontologically to Realism: The *empirical* being the frustration of the user (and friends) with the system and the action taken of re-parking the car. The *actual* being the design that activates the two-hour parking limit. Epistemologically, we now pivot to Relativism by looking at the *intransitive* dimension of the *real* domain and attempt to analyse the causal power(s) of the generative mechanism(s): Why are the two actions in the *empirical* domain taking place?

The easy (deductive) answer would be "because the *rule* forces the behaviour that then leads to the user's attitude". But the *rule* is a sociomaterial assemblage, a CR structure, that was devised based on a goal that can be noticed through retroduction between the *real* and the *empirical* domains. Informant C3 tells us: *"We [the city of Santander] want for as many people as possible to park their cars. Once we had too many people parking, we limited the time to two hours."* This shows us one 'tile' of the imbrication within the entangled assembly: the city's goal is to maximize parking for as many users as possible.

Through Analytical Dualism, we now look at the dimension of time. The interview data suggests that we can separate the entangled assembly into two basic slices of time: ‘before the change’, i.e., before the introduction of the rule, and ‘after the change’. The Santander Smart City plans, reviewed by the researcher, show that this rule change took place in 2015.

7.2.1.8 Time-phased instantiation # 1

For the time period before the change, meaning before 2015, we know from the interview data that there were *“too many people parking”*, which leads us to assume that the system was overloaded and that there must have been frustration among users caused by not finding a parking space. This suggests that parking space shortage (Material Agency) influenced people’s attitude (Human Agency) as expressed through **arrow 4**.

As a response to the problem, the city planners then implemented the ‘two-hour rule’.

7.2.1.9 Time-phased instantiation # 2

From 2015 onwards, we see that the attitude is still one of frustration, but that the cause has shifted where users are unhappy with the system’s design that now enforces the time limit. Here, the design (Interpretive Schema) influences people’s personal attitudes towards the system (Human Agency), which points to **arrow 2**.

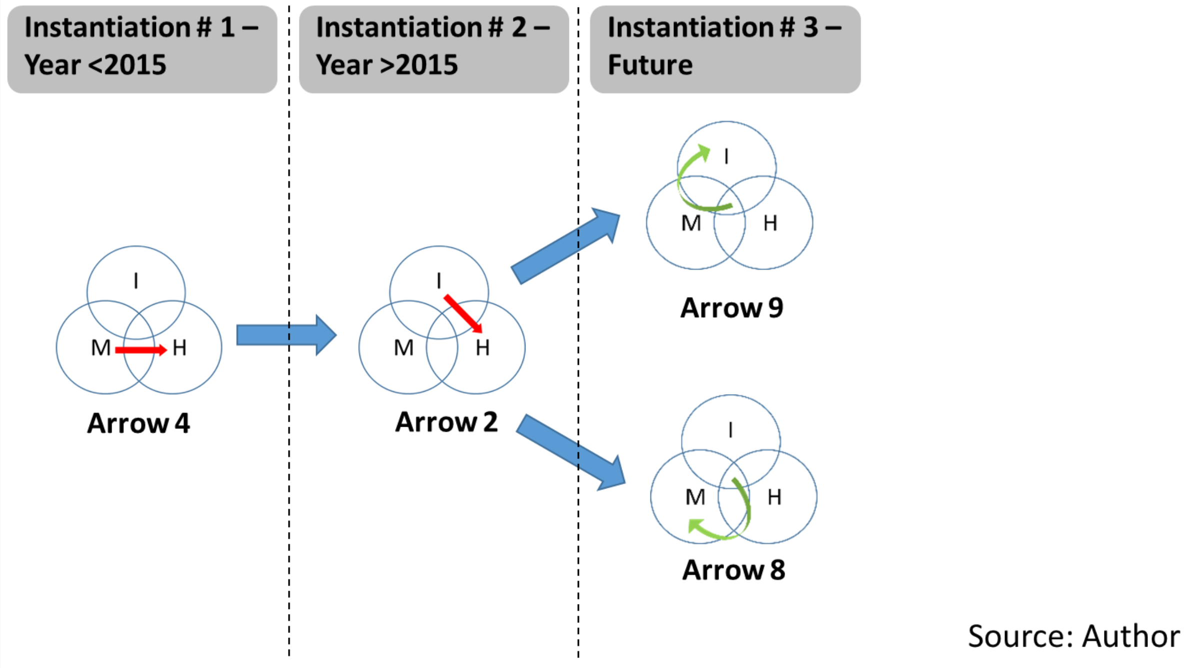
7.2.1.10 Time-phased instantiation # 3

This ‘time slice’ is a prediction of the future with a proposed design change by the researcher. The suggested modification aims at better aligning the city’s goal of enabling maximum parking opportunities for a maximum number of people with the ‘two-hour rule’. The rule only makes sense if there is a shortage of parking spaces in the area. If there is not, then a car that is parked for more than two hours would not prevent another driver from obtaining a spot since spots would be available anyway. The solution is for the ‘two-hour rule’, expressed through circle I, to be activated dynamically based on traffic volume (circle M). This would balance the enablement of more residents and visitors to park their cars with the convenience for drivers to be able to stay longer than two hours, if desired. This future scenario aims at a change to **arrow 9** (formation of new design) and **arrow 8** (formation of new technology).

7.2.1.11 Temporal flow of time-phased instantiations

We can graphically depict the three time-phased instantiations in Figure 7.2:

Figure 7.2 – Time-Phased Instantiation of UC 'Two-hour parking max. alters behaviour'



The influence of the design (Interpretive Schema) on people's attitude (Human Agency) formed two ideas:

1. Change the design to restrict the application of the 'two-hour rule' to only apply during times of high parking loads.
2. Implement this solution in the system (Material Agency).

Since this section outlined how the SBF can help in understanding generative mechanisms at work, the subsequent section returns to examining UCs that were generated as a result of differences between intent and design versus use.

7.3 Research sub-question 1: What are the unintended consequences and their evidence based on intent and design versus use?

"Where the action has results that are not part of the actor's purpose."
(Merton, 1936: 901)

The systematic analysis through arrows 1 through 6 of the SBF shows the value that can be derived from examining the framework's pathways. By doing this, project teams can avoid potential issues early in the project cycle, i.e., during the conceptualization and planning phases; thereby minimizing negative UCs upon implementation. The findings of the Santander case study and the thought experiments in Chapter 4 have shown that, for the system to work effectively, all six arrows (pathways) of the framework ought to be considered when devising the system's design. Note that arrows 7, 8, and 9 deal with the formation of new routines, new technologies, and new norms, rules, laws, designs, and standards. **As such, these three arrows represent pathways originating from the sociomaterially entangled middle that have been traced through arrows 1 to 6 with the help of Analytical Dualism.**

Arrows 1 through 6 show the process of analysis based on actual findings of the Santander case study as well as the thought experiments of the technology-enabled car park and the Eaton *et al.* case study in Chapter 4.

Arrow 1, where Human Agency influences Interpretive Schema, applies to situations where personal routines, habits, dispositions, and opinions are not in line with the existing set of norms, rules, laws, designs, and standards. In the case of Santander, arrow 1 was implicated where a rule was considered unfair (see Section 6.2.7). In this case, the COVID-19 lockdown drastically changed the parking situation in the city, yet existing rules were not modified, which in turn caused the perceived 'unfairness' in the user community, that then gave rise to people's desire to change the rule. In the Eaton *et al.* case study, Tables 4.2 and 4.3 show two other occurrences of 'unfair' rules where developers communicated their strong disagreement to Apple, causing the company to eventually change their practices.

One way of testing for cohesion between Human Agency and associated Interpretive Schema is to do a sequential bidirectional assessment. This is part of CR's principle of retroduction by gathering empirical corroborative data to ensure a sufficiently close conjecture regarding causal generative mechanisms. Here, one starts with defining strategic expectations of the system and a recording of all applicable use cases. For each expectation or use case, the question then becomes as to what degree the extant rule set supports the expectation or the requirement. It is a 'what if' application of the 'rule' in comparison with the desired 'effect'. Ultimately, this would result in proposing new rules or modifying existing ones to stem trust erosion in the system as the outcome of this UC.

As a counterflow to this, **arrow 2** (Interpretive Schema influencing Human Agency) takes each existing rule (formal or informal) and examines its 'fitness for purpose'. This would then either result in changes to the existing rule set through arrow 1 or in an attempt to influence people's habits and behaviours such as is the case with arrow 2. The Santander data has shown that most UCs resulted from rules or design decisions that did not support people's expectations or habits with regards to the automated parking system. The data suggests that users should have been involved much earlier in the design process. Not only would this have increased the likelihood of a fitting design that is in line with user's expectations, but it would have also contributed to a sense of ownership within the user community. As identified in the Eaton *et al.*

case study, Apple's restriction of limiting third-party applications caused a negative reaction among the user community.

Specifically for arrow 2, where there are differences between the rule, design, or norm, and people's interpretation or adherence, it is helpful to probe for 'faithful' (as expected) versus 'unfaithful' (unexpected) usage of technology (DeSanctis and Poole, 1994: 129-130). Wanda Orlikowski subdivided unfaithful technology usage into errors and intentional unfaithful usage. The former would be due to misperceptions, lack of understanding, or slippage and the latter would relate to sabotage, inertia, and innovation (2000: 409).

Aside from the appropriate fit of the design the **arrow 3** pathway (Human Agency influencing Material Agency) deals with whether the system's basic affordances (or constraints) fit with how humans intend to use the system. The primary concern here is context that impacts whether a system's given affordance is considered helpful or a hindrance in the appropriation process (Faraj and Azad, 2012: 12). Over time, increased demand or change requests from users are likely to cause design modifications of the object to accommodate this change. Human Agency does therefore have a direct influence on Material Agency by increasing its scalability and flexibility (Tilson *et al.*, 2010: 5).

As found in the Santander case, the questions here go beyond the detailed design into larger ramifications of technology choice. One aspect dealt with the automated scanning vehicles that proved to be less efficient in crowded spaces and that caused adverse reactions among residents who 'tried to outrun' the vehicles to avoid a fine.

Despite a perfect design, basic system affordance limitations can constrain how an application is used, an imbalance that would be raised through **arrow 4** (Material Agency influencing Human Agency). In Santander's case, the problem again related to sensors and their high error rate when detecting the placement of objects above them. This is arguably the biggest issue in Santander's parking solution: unreliable sensor readings consistently erode trust in the system.

Arrow 5 (Interpretive Schema influencing Material Agency) entails the influence of the existing rule set on technology choices and their affordances. Four themes have transpired in the Santander case study: Legal ramifications, ethical considerations, usability (design) questions, and affordability concerns. Conversely, **arrow 6** (Material Agency influencing Interpretive Schema), involves a creative brainstorming process to crystallize how advances in technology (Material Agency) could widen the network of Interpretive Schema. We apply the process of retroduction with the central question being whether all available affordance features of a technology have been considered in the design of the solution. This is consistent with retroduction's creativity and intuitiveness that takes interpreted beliefs of actors in the process into account since these actors apply their *transitive* interpretation to the *intransitive* mechanism(s) in question (Wynn Jr and Williams, 2012: 800).

7.4 Research sub-question 3: What is the intended impact of using an IoT car parking solution within the context of a Smart City?

"When it works, then there is no problem." (Informant R2)

This section contains two parts: It first explains the intended impact of using an IoT parking solution in the Smart City of Santander. This is based on the study of Santander's strategic plans for its Smart City implementation, the design documents created by the city administration and the University of Cantabria, financial plans, and other artifacts. What follows in the second part is a compilation of principles and key lessons that are transferable from Santander to other Smart Cities.

7.4.1 Intended impact on Santander

There are 21 identified goals that the city, service provider, and users expected from the Smart City implementation:

1. **Make lives better for citizens:** Overall, the Smart City initiative is seen as a success in Santander particularly in the fields of water management, public park irrigation, waste transportation, and automated street lighting. Due to the COVID-19 crisis, tourism in the years 2020 and 2021 was negatively affected, which also had an impact on Smart Parking. Interviews with users revealed that many people appreciate the ease of use and convenience that comes with the parking solution, but that the sensor-based availability picture is often mistrusted and therefore not used.
2. **Traffic decrease:** The city has met its long-term goal of reducing congestion. It is unclear as to how much the new parking solution versus other improvement initiatives contributed to this goal. In conjunction with the new parking system, the city has also embarked on making Santander more bike friendly, providing additional public transportation options from surrounding areas into the city centre, and generally advancing Santander's agenda of becoming a 'green city'.
3. **Temporal spread of parking load:** The city incentivized drivers to use street parking during off times, for example on Saturdays. Interviews of business owners highlighted that the city reached this goal successfully. Informant R16, a store owner, remarked that *"lunchtime traffic used to be crazy, but now more people come on Saturdays because [parking] is cheaper in the city".*

4. **Fairness in parking opportunities:** The two-hour maximum parking time limit during peak periods enforces the ongoing rotation of vehicles. This has helped with more people obtaining a parking spot. However, this rule remains to be in place if the parking volume is low; thereby, leading to the UC of people having to re-park their cars in a different (nearby) spot if they desire to remain in the area past the two-hour mark.
5. **Fairness in parking fines:** The automation of the ticketing process for fines now prevents human enforcers from exercising subjective judgment. Writing a parking violation tickets is no longer at the sole discretion of a patrol officer, who may choose out of his or her own volition to issue a ticket to one person but not to another one. Now, through automation, bias has been largely removed. The automated scanning vehicle detects a parking violation and the officer processes the ticket based on the captured record in the database. There is now also better proof for when a parking violation occurs. Based on the record that originates with the scanning vehicle, officers are obliged to take three pictures of the offending car to prove its location and non-movement.
6. **Better response to citizen requests:** This is a larger positive side-effect beyond parking. The city is now able to respond to citizens with quantitative data and is also able to create and update rules based on this information. Since the Smart Santander database collects vast amounts of data on all facets of the Smart City, citizen's requests and complaints can be answered with more factual background information. The database can be queried by the city and the public, this includes potential (new) service providers as well as University researchers.
7. **Better overall mobility:** As described under item # 2, the city has met its goal of reducing congestion in the city centre. The presence of fewer cars directly contributes to increased mobility in the city centre.
8. **More parking spaces:** While the actual number of parking spaces in the downtown area has not increased (it remains static at 375 spaces), the usage load of these spaces has changed for the better. One example of this is the enforced two-hour parking limit during peak hours and the fact that users pay for the actual parking time instead of pre-paying for a block of time in advance. In the pre-payment scenario, users tend to stay longer to take full advantage of the money that was already paid.
9. **Real-time picture of parking spots:** Several interviewees reported that the real-time availability picture of parking spots is unreliable. The Smart Santander application is therefore generally not trusted when it comes to availability information. The street display panels that provide the count of available spaces in the area, and within a street, are also regarded as inaccurate.

10. **Secure and easy information for drivers:** Given the problems with real-time availability picture of parking spaces, many interviewees do not agree that this performance objective has been met.
11. **Smart Santander application:** The application is used extensively for processing parking payments but less so in obtaining the parking availability picture. The Smart phone application is considered robust and available close to 100% of the time, which is in achievement of its goal, and previous performance issues with the application were largely resolved. The application is seen by citizens as an improvement.
12. **Fairness in payment of parking time:** People appreciate the fact that they now only pay for the actual time parked. In the previous manual solution, a driver had to pre-pay a certain amount of parking time and no refunds were issued if the time was not fully utilized.
13. **Panel information:** Interviewees trust the street panels more than the Smart Santander application, but only for approximate guidance. Drivers generally do not seem to trust the displayed count of available parking spaces.
14. **Payment of fines:** Parking violation tickets can now be paid through the application with the credit card on file. This is much simpler than the previous process that required a bank transfer or a visit to the service provider’s office.
15. **Cashless payment:** This has been accomplished through the Telpark application as well as through parking terminals that have been conveniently placed in the streets.
16. **Ease of obtaining residential permits:** Dornier replaced a convoluted manual application process that required residents to visit the service provider’s offices with an application that significantly streamlines requesting resident parking permits.
17. **City and service provider skill increase:** Citizens and employees of the service providers and the city administration had to learn new skills to interact with the new technology.
18. **Efficient parking administration:** This goal has also been achieved by using automated scanning vehicles. In cases where high traffic volume impacted the efficiency of scanning vehicles (approximately 20% of the routes), human patrol officers were reinstated. Street parking terminals keep track of how much money has accumulated inside and cash pick-up is now scheduled based on need.
19. **Data for commercial purposes:** Through the Smart Santander database, the city now has up-to-date information on parking usage. This aids the city administration, as an example, in making decisions regarding road closures (location and timing) and placement of waste receptacles that could impact available parking spaces.

20. **University research benefit:** The University of Cantabria's School of Industrial Engineering and Telecommunications has been an active participant in the development of the Smart City. The school successfully incorporated IoT technologies into their curriculum and student enrolment increased.
21. **More innovation and technological advancement:** Some service providers have successfully pivoted from pure service provision to becoming a technology company. However, as one finding of a UC has shown, there are companies that were simply not able to create the technical know-how to compete.

In summary, the Santander Smart Parking solution has met its goal of reducing congestion in the city centre, ensuring that more parking spaces are available to more people, and providing convenient ways to interact with the Smart Santander application. The city could have avoided a number of UCs if the project team had systematically considered the pathways of the SBF for foresight and planning. The system's propagation of 'fairness' is appreciated: users only pay for actual time parked rather than pre-paying for blocks of time that may not be used. Parking violation cases are determined by the system rather than based on the discretion of human patrol officers.

The biggest problem area of the system is that the sensor-based parking space availability picture is generally not trusted by users. This applies to the Smart Santander application as well as to the street panels that display parking space availability information. It severely undermines trust in the application, which is exacerbated by rules where their reasoning is not easily understood, such as enforcement of the two-hour parking limit in the presence of sufficient parking availability.

Users welcome the cashless payment for parking spaces and faster and easier ways, if needed, to settle fines and obtain residential parking permits. Overall, the city and service provider are viewed as more responsive than before the system's introduction.

There are other benefits for the city and the service provider: higher efficiency through automation, available sensor data for analysis (data mining), and a general skills increase amongst their employee bases. The University of Cantabria benefitted from overseeing the technical program and incorporated a technical IoT portion into their telecommunications curriculum.

7.4.2 General intended impact (transferability to other cities)

The network of a Smart City is highly complex with many processes being enacted in a semi-autonomous fashion that resembles Artificial Intelligence (AI). This puts emphasis on an overarching and thorough design that bounds the city's network (Kok *et al.*, 2009: 2). Sensors are vitally important for any IoT system in that sensors are its 'eyes' and 'ears' and control what actions the system will take since a *"Smart City senses and acts in an instrumented and interconnected fashion"* (Bowerman *et al.*, 2000).

The team in Santander, at the start of the Smart City project, decided to implement ferro-magnetic underground detection sensors. At that time, Spain's data privacy law restricted the usage of cameras in public places and the decision thereby equally restricted Material Agency from the start of the project. Magnetic underground sensors have a high error rate and are technically inferior to camera-based systems. Figure 1.1 in Section 1.2 shows a Venn-diagram signifying the desired balance between instrumentation, interconnectedness, and intelligence inside a Smart City (Harrison *et al.*, 2010). Santander enjoys benefits of its Smart City technology such as some user satisfaction, new efficiencies, cost savings, and positive environmental impacts (Doran and Daniel, 2014: 61), but its path dependence in choosing underground sensors resembles an imbalance in the 'instrumentation' circle of the Venn-diagram. Magnetic sensor readings are simply not reliable enough and thus undermine the user's confidence in the system. The first suggested and transferable lesson for other Smart Cities is therefore to consider the more advanced technology of a **camera-based system**.

It is advisable for any city, which is embarking on an IoT project, to reach out to other cities to learn about their experienced positive and negative effects. For this exercise, one can transpose an **iterative 'what if' cycle** (borrowed from retroduction) and use creativity and intuitiveness to explore how another city's practice relates to one's own planned IoT implementation. This constitutes a reframing of Danermark *et al.* – instead of *"utilizing the Critical Realist frame by hypothesizing the necessary structures and mechanisms consistent with the previous abstraction."* (2002: 109), we build hypotheses with necessary structures and mechanisms for 'Smart City x' by comparing it with 'Smart City y'.

The next recommendation is to conduct a **'dry run'**, i.e., a paper-based walkthrough, after design finalization. This consists of meetings with user **focus groups** that specifically probe into people's reactions and anticipated behaviours when being confronted with certain aspects of the design. The potential question to ask during the 'dry run', for each rule, would be whether the focus group participants understand what the rule intends to accomplish. Subsequently, the team members could be asked if they agree with the rule. Is the rule in question still timely and does it link up with the problem to be solved? Are there other means to accomplish the same result? And what would likely happen if the rule was not in place or if it was not enforced?

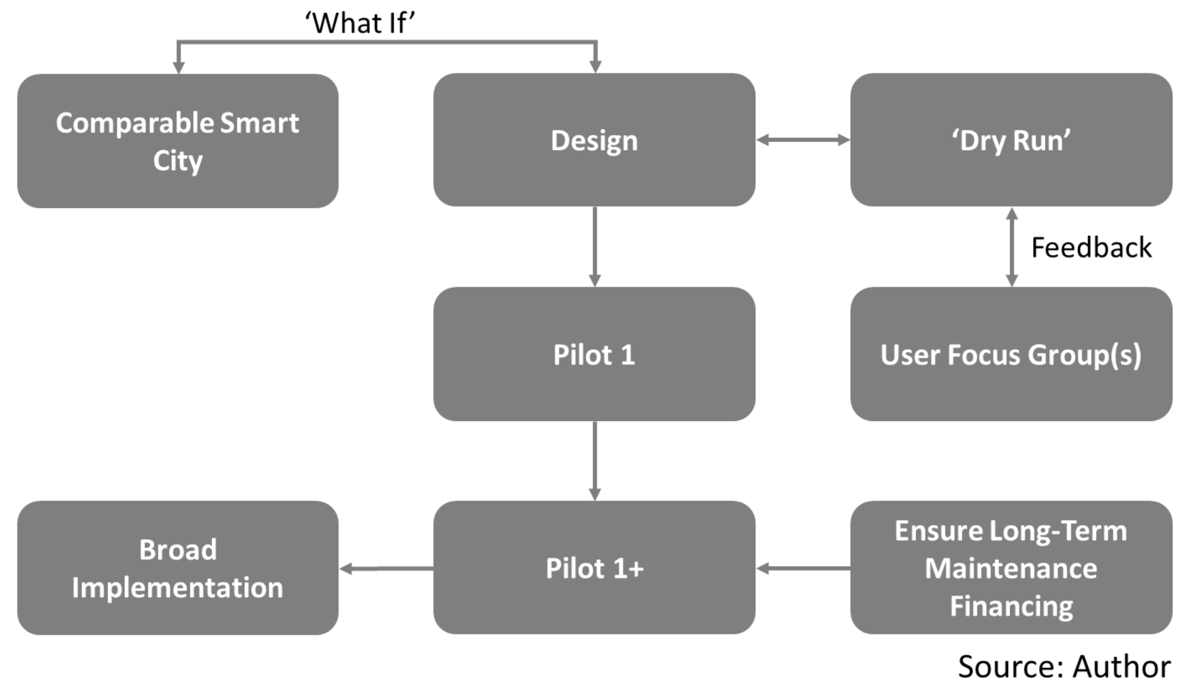
What should follow is a **pilot**: The Santander project team conducted a pilot implementation with underground sensors. However, this took place in a controlled environment in the University of Cantabria's parking lot. The pilot team participants parked their cars with sufficient precision on the sensors, all cars seemed to have had the required metal density, and motorbikes (where inexact placement on sensors is frequent) were not used by the testers. Given these conditions, the prototypal experiment achieved a high success rate. It is crucial for the **pilot to be realistic** and for it to resemble actual usage conditions. If the team had tested a small number of sensors *in vivo* in the city streets, the technology's shortcomings would likely have been found sooner.

It is also good practice to conduct more than one pilot and with **successive increases in the pilot's size.** For example, after a pilot of x devices, a second phase should add more devices, and phase 3 should further increase the scope of the test. Such a controlled implementation would also provide opportunities for correction before moving to a consecutive phase.

It is also imperative for Smart Cities to plan ongoing support and maintenance requirements (and funds) for systems. The Santander study confirmed that the basic technology choice should not be regarded as a one-time event. Ongoing maintenance requirements and their associated cost need to be considered. Santander has experienced a lack of maintenance for its Smart Parking infrastructure (sensors, terminals, street display panels), prompted by a lack of funding, that has further led to the user's erosion of trust in the system.

What follows as a last step is the actual system implementation. The model in Figure 7.3 summarizes the recommended steps for Smart Cities to achieve their intentions:

Figure 7.3 – Recommended Steps for Smart Cities to Achieve Intended Impact



The SBF allows for a proactive 'what if' exploration of scenarios during pivotal stations within the project flow: Design, 'dry run', and pilot(s).

During the design phase, there would be a logical step-through of arrows 1 through 6 that ought to trigger a series of conceptual questions. For **arrow 1**, this would be how Human Agency influences Interpretive Schemas. In the context of a Smart City, it would prompt the designer(s) to confirm if existing norms, rules, standards, etc. are structured in a way where they best accommodate people's interaction with the technology. Conversely, for **arrow 2**, the question then becomes if any of the extant regulatory, standards, or design framework is out of line with how users are likely to apply the envisioned technology. **Arrow 3** would prompt the question whether technology choices for the solution are best aligned with the user's dispositions, skills, abilities, etc. In the case of a Smart City, this includes the most optimal technology choice for the sensor infrastructure network (for example cameras versus ferro-magnetic underground sensors). In a confirmatory step, **arrow 4** can be used to question whether the technical setup will in fact satisfy how humans intend to use the technology. **Arrow 5** highlights where the existing normative framework is not in line with the technology offering. **Arrow 6**, as a complement, would point to rules and standards that have to be devised or altered to ensure that the employed technology is used as intended.

Once the design has been validated by working through all six arrows of the framework, the same question complex can be revisited during the 'dry run' phase. The main difference is that questions (and answers) extend from the designer's point of view to users (for example with the help of focus groups), which provides a different perspective. Therefore, while the steps within the framework remain essentially the same, for example in comparing and contrasting Human Agency with Interpretive Schemas in arrow 1, and Human Agency with Material Agency in arrow 3, etc., the scope widens significantly. This is especially true if the 'dry run' is conducted with future users of the system who envision how the technology might conform to, or be out of line with, their needs.

The scope is further elaborated by moving from the 'dry run' phase to an actual pilot once the initial prototype of the solution has been constructed. It is expected that the pilot phase will provide even richer examples that can be evaluated by utilizing the SBF – especially if the pilot setup closely mimics the real conditions of the subsequent (full) implementation. In the case of Santander, if sensors had been tested in live conditions that include inexact parking of vehicles, using motorcycles, etc., the issues in the arrow 4 pathway would have been discovered much earlier. This arrow shows the influence of Material Agency onto Human Agency. By comparing and contrasting the existing affordance of the sensor (Material Agency) *in vivo* with how humans park and use these sensors (Human Agency), the imbalance between these two circles of the Venn diagram would likely have surfaced.

After go-live of the system, the SBF can be used to attempt to uncover generative mechanisms behind observed phenomena. The following section, that answers research sub-question 4, will include a hypothetical example of how the SBF can be applied to probe for potential future constellations in the triad of humans, technology, and structure, that could lead to UCs.

7.5 Research sub-question 4: What suggested actions could minimize unintended consequences and improve the design and interaction with IoT Smart City technologies?

"Make it better." (Informant R8)

There are 16 suggested improvement actions that apply to Santander and that could be leveraged by other Smart Cities in comparable contexts. The summary of these is included in Table 8.1 of Section 8.1 and details are provided in Appendix A. The true value of the SBF lies in its potential to be applied to other scenarios and problem constellations that present themselves. This is illustrated through a thought experiment that further builds onto the latest time-phased instantiation of the UC 'Expected parking space unavailable' (see Section 6.2.1.6).

For this thought experiment, let us assume that Santander now plans to migrate the existing Smart Parking solution from underground sensors to cameras. The underground sensors represent a historical path dependence since the law did not allow for camera installations at the outset of the Smart City program. From the perspective of Analytical Dualism, this characterizes an existing structure that impairs present agency and enables or constrains future choices. We can use the SBF to proactively check for potential UCs before the system is altered:

In focusing on **arrow 1** (Human Agency's influence on Interpretive Schema) – the main question revolves around how people's dispositions and/or personal routines can be accounted for in the design and standards of a solution. We know from previously collected data in Santander that there is general concern relating to privacy and the usage of cameras. There are at least two problem areas that this arrow highlights: 1) optical recognition of images that extends beyond license plate capture of a parked car and 2) duration and security of storing such information. Given this circumstance, the design team would want to put standards in place that prevent capturing facial features and limit the storage of license plate information beyond a certain time duration.

In continuing with this hypothetical scenario, and in contemplating **arrow 2**, the project team would want to influence public perception (Human Agency) with relevant aspects of the chosen design (Interpretive Schema). One approach would be to make sample camera images available on a website or in a public place such as the city's visitor's centre. These sample images would be helpful in convincing people that facial features are in fact not recognizable on the images. The team could also publish rules regarding duration and practices of data storage and elaborate on safety mechanism that will be put in place to protect data from unauthorized access.

The meaning of **arrow 3** is how Human Agency shapes Material Agency while **arrow 4** addresses the reverse scenario. One idea here is the installation of a safety feature on top of the camera that may further alleviate people's concern with using this technology. This feature could consist of a cone-shaped device around the camera shutter to physically restrict inadvertent imagery beyond license plate numbers. **Arrow 5** (Interpretive Schema influencing Material Agency) would, in this example, encompass all design elements dealing with a more secure solution that need to be incorporated in the technical end-product. **Arrow 6** would be the camera's affordances and constraints (Material Agency) influencing the design. The project team would want to think about the requirement to read license plates in all lighting conditions. How would the design have to incorporate the reading of license plates at night or during adverse weather conditions such as heavy rain or intense fog?

This thought experiment, that builds upon the actual Santander data, shows how the SBF serves as a 'blueprint' for systematically examining each of the six pathways connecting the circles of the Venn-diagram. The framework facilitates a deeper understanding of the action patterns in a dynamic system where this dynamism stems from the amalgamated interactions between users and designers with material affordances – under the canopy of the normative framework.

7.6 Summary of discussion

Robert Quillen: "Discussion is an exchange of knowledge – an argument, an exchange of ignorance." (Bernhard, 2009: 491)

This Discussion chapter took the detailed case data and transposed it to a higher level of abstraction. Through the SBF, we answered the second research sub-question by highlighting potential generative mechanisms of UCs. It is important to note that the case data only permits the <u>tentative articulation</u> of causality (Eisenhardt, 1989: 532, 536). The generative mechanisms are represented with varying degrees of certainty in their arguments, whether they are abductive, inductive, and retroductive in nature. It is helpful to recall CR's recognition of a demi-regularity, or partial event regularity, where common structural and contextual factors may lead to similar experiences. Even if there is no predictable match, demi-regularity opens up the possibility of causality of the implicated mechanisms and structures (Lawson, 1997: 30-32). The causality assumptions could be further strengthened through a retrodictive case study that colligates observable data with existing theory by exercising concern for surfacing the unobservable mechanisms at an abstract level (MacCorquodale and Meehl, 1948: 95).

The suggested generative mechanisms apply to Santander and the point in time of data collection. For example, other countries may have less restrictive data privacy laws regarding camera usage. In addition, camera and sensor technologies have evolved, which goes hand-in-hand with an improvement in system accuracy. Another municipality may not have restricted parking to a maximum of two hours during peak times, etc.

What is more readily transferable to other Smart Cities, and other technologies beyond IoT, is the application of the SBF to conduct the analysis. The sociomaterial vantage point on the described scenarios in this chapter convinces us of the assimilated boundaries between users, designers, technology, and norms where changes to the system (such as the implementation of the 'camera enhancement') will rise from the entangled middle space. Analytical Dualism will guide us to examine a slice of the time-phased instantiation, i.e., the migration from sensors to cameras. The SBF provides us with the connecting tool for approaching the constitutively entangled slice of a morphogenic sequence. It is the framework with which we can examine the multi-layered inferences between Human Agency, Material Agency, and Interpretive

Schema that are represented by the inter-circular directional flows of the SBF. The final chapter summarizes the conclusions of the study and closes out the work.

8 Conclusions

“When the tailor is good, the coat will fit.” (Schumpeter, 1908: 527-528)

8.1 Summary of contributions and answers to research questions

“A theory […] is a device of sudden enlightenment. It is complex, defamiliarizing, rich in paradox. Theorists enlighten not through conceptual clarity but by startling the reader into satori.” (DiMaggio, 1995: 391)

Over the past twenty years, a multitude of cities across the globe progressed in their quest of becoming a Smart City by creating efficiencies, improving sustainability, advancing economic development, and enhancing the quality of life for their residents and visitors (Ramaprasad *et al.*, 2017: 14). The prime enabler for these endeavours is the Internet of Things (IoT) that allows cities to become ‘smart’ through instrumentation and the interconnection of sensors (Harrison *et al.*, 2010: 1). IoT systems advance into the realm of Artificial Intelligence by virtue of their sophisticated design and human-like thought processes, which is a development accompanied by a plethora of unintended consequences (UCs). The aim of this thesis is an exploration of these UCs in the human-technology interaction and in the context of an IoT system within a Smart City setting. The review of the literature found a gap in how these UCs can be identified, analysed, and ultimately avoided to aid future Smart City implementations in learning from prior projects.

Researchers such as Wanda Orlikowski, Susan Scott, Olga Volkoff, Wiebe Bijker, Dubravka Cecez-Kecmanovic, Daniel Robey, Gerardine DeSanctis, Marshall Scott Poole, Youngjin Yoo, Claudio Ciborra, and many others, broke ground early-on by recognizing a need in IT research – an approach that is fitting for the complex and multi-layered interactions between technology, human agency, and structure. The revolutionary meta-theory of Sociomateriality represents an alternative to other research concepts that traditionally regard ‘technology’ and ‘people’ in a less interwoven fashion. Sociomateriality espouses the entanglement of technology, human agency, and structure. This entanglement is especially present in fast moving emergent technologies, such as IoT, that can allow detrimental UCs to emerge when the complexity of the system cannot be analytically disentangled. Researchers have been grappling with the question of how to draw out generative mechanisms formed in the interaction between powers and tendencies inherent in structures and agency.

This research provides an answer to this question by showing that Sociomateriality can be paired with Analytical Dualism with the backdrop of Critical Realism (CR). The latter provides the foundation for this pairing in that it looks at *reality* through a stratified lens that distinguishes *the world* from what we *know about the world*. CR thus separates the ontological 'real', that contains (hidden) generative mechanisms, from the epistemological 'relative', that comprises the varied experiences of how we perceive this world to be.

The central ingredient in this distinction is the dimension of time, which enables us to analytically dissect the constitutive entangled experiences, emphasized in Sociomateriality, into morphogenetic time-phased instantiations that separate structure from action and from subsequent structural elaboration. This is accomplished via Margaret Archer's concept of Analytical Dualism (2010) as a proposed pivotal extension to the concept of Sociomateriality.

The novel combination of complementary approaches leads to the first contribution of this research: The **Sociotechnical Behavioural Framework (SBF)**. It was built by exploring several tributary theories to Sociomateriality (Affordance Theory, Structure and Duality, and the Structurational Model of Technology) and allows for the formation of abductive inferences of mechanisms and tracing them through the interactions between Material Agency, Human Agency, and Interpretive Schema. The creation of the SBF answers part of the second research sub-question: *"how can potential generative mechanisms behind unintended consequences be modeled?"*

Since this framework did not exist before, it was prudent to further explore its function by retroductively testing the abductively derived results. This was initially done with three thought experiments: by using it to analyse processes in a technology-enabled (imaginary) car park, by applying it to an existing case study by Eaton *et al.* (2015), and by using it again in a comparative setting of an imagined manual car park.

The SBF was further strengthened through an extensive case study of an IoT-based car parking system in the Smart City of Santander, Spain. The case study gathered primary data from system designers, operators, city officials, and parking system users. All pertinent processes within the Santander Smart City were captured through process flow charts and data flow diagrams that documented the 'design' aspect. This was then compared with actual data regarding 'use' of the system by applying the SBF. The procedure led to the second contribution of the thesis by identifying **30 actual findings and 16 UCs**. It also answered the first research sub-question of *"what are the unintended consequences and their evidence based on intent and design versus use?"*

The SBF allowed isolating the properties of each discovery, systematically reasoning for their occurrence, and suggesting their generative mechanisms. This then provided the full answer to the second research sub-question: *"what are the potential generative mechanisms behind unintended consequences?"* What followed was the SBF's substantiation through a Context – Mechanism – Outcome analysis (Pawson and Tilley, 1997) and (Dobson *et al.*, 2013: 981-984) and a Time-Phased Morphogenetic View (Archer, 2010: 238) that compared, for each circle of the SBF's Venn diagram, the pre-existing structure, the observed action, and the resulting structural elaboration. It thereby transposes the anticipated mechanism into a structural view that is expressed pre- and post-action. This resulted in specific practical learnings and recommended improvement suggestions for Santander and for cities in comparable contexts.

The third contribution of the thesis consists of recommendations and a methodology for other cities to learn from Santander and to limit the occurrence of UCs in sociomaterial systems. Santander set out on their Smart City parking journey with the aim to make lives better for its citizens through a reduction of traffic and an improvement in parking mobility. At a more tangible level, this meant spreading parking demand more equitably across the city centre, ensuring equal opportunities for citizens and visitors to obtain a parking spot, and fairness when it comes to paying for parking time (or fines in the case of infractions). The answer to the third research sub-question: *"What is the intended impact of using an IoT car parking solution within the context of a Smart City?"* is provided in the Discussion chapter (Section 7.4). What is paramount here is the question of transferability to other municipalities. Cities with a different age, geography, climate, or other elements that represent path dependence may have different intentions, goals, and objectives. Figure 7.3 in Section 7.4.2 contains a generic model that can guide a Smart City towards the realization of the intended impact by avoiding UCs.

With similar caveats pertaining to the transferability matter, the answer to the fourth research sub-question *"what suggested actions could minimize unintended consequences and improve the design and interaction with IoT Smart City technologies?"* is summarized in Table 8.1:

Table 8.1 – Suggested Improvement Actions to Minimize Unintended Consequences

Unintended Consequence	**Suggested Improvement Action(s)**
Expected parking space unavailable	Utilize a technology that captures parking space availability with great accuracy
User frustrated by fine	Machine-readable license plates or user validation prompts to minimize entry errors
User outruns scanning vehicle to avoid fine	Educate users and safety training for scanning vehicle operators

Table 8.1 – Suggested Improvement Actions to Minimize Unintended Consequences	
Unintended Consequence	**Suggested Improvement Action(s)**
Drop in scanning vehicle efficiency	Dynamic reallocation between scanning vehicles and human patrollers based on throughput efficiency
User non-involvement fostered resentment	Ensure wide-ranging input at the program start from residents through focus groups and a visitor centre
Disruption of routine causes frustration	Institute a change/management program that clearly communicates benefits of the new system to all parties involved
Unrelated fee increase caused user resentment	Up-front change/management initiatives and minimize simultaneous changes, i. e., ‘change fatigue’
Anonymity of system is conducive to cheating	Appeal to people’s ‘sense of fairness’ in addition to presence of human patrol officers
General parking space unavailability	Frequently assess division between resident and visitor parking spaces
Users unfairly pay too little or too much for parking	Examine mapping of streets to parking zones to ensure homogenous parking volume for dynamic pricing rules
Service provider’s proposals are unrealistic	Ensure a Governance process (with all stakeholders) to prioritize projects based on needs
Project cost exceeds estimate	Use standard project estimation techniques by identifying upper and lower boundaries, probabilities, and planning for buffers

Table 8.1 – Suggested Improvement Actions to Minimize Unintended Consequences	
Unintended Consequence	**Suggested Improvement Action(s)**
Unscheduled roadwork decreases profit	Bundle road maintenance work and conduct repairs during low-volume parking times (nights, holidays)
Smaller pool of potential service providers	Aid non-technical service providers who need help (documentation, FAQs, and PMO support)
Two-hour parking maximum alters behaviour	Suspend time-restriction rules when sufficient parking spaces are available (feedback mechanism in the system)
Delayed compliance checks conducive to rule breaking	Appeal to people's 'sense of fairness' and increase frequency of control vehicles

In summary, this section provided answers to all four research sub-questions and thereby a response to the overarching problem statement: *"What human technology interactions generate routes to unintended consequences in IoT parking systems within Smart Cities?"*. The section also summarized the three main contributions of the thesis: 1) an original framework to analyse UCs and their purported generative mechanisms, 2) tangible learnings from the Santander Smart City case study, and 3) recommendations and a methodology for other cities to further apply these lessons in a comparable context.

The next sections within this chapter further expand on the limitations of this study, provide ideas for future research, and close with the researcher's reflection on the work.

8.2 Limitations

"It is not only best for authors to acknowledge their study's limitations […], but proper framing and presentation of limitations can actually increase the likelihood of acceptance." (Ross and Bibler Zaidi, 2019: 263)

One important limitation of this study, rooted in its design, stems from the fact that it is confined to the single *in vivo* case of Santander. This raises the question of transferability of findings to other cities and whether the SBF has been used with sufficiently heterogeneous data to assess its efficacy across a wide array of findings. The approach represents a conscious choice by the researcher since widening the scope to other cities, potentially with conducting a cross-case analysis, would have significantly prolonged the work. This constraint was alleviated through the application of three additional data analysis sources that aided in triangulating the Santander case study findings (see Chapter 4). The first was applying the SBF to a thought experiment surrounding a technology-enabled car park. Then, the SBF was used on an existing case study by Eaton *et al.*, which provided the auxiliary benefit where Eaton *et al.* was originally conducted following a Yin/Eisenhardt approach. The same method was used by the researcher in the Santander case and thus Eaton *et al.* served as an early validation for combining Yin and Eisenhardt. The third validation step occurred through another thought experiment of using a manual car park as an additional 'case' where the data was also analysed through the SBF. This was advantageous in that the manual setting served as contrast to the automated car parking model of the *in vivo* case study.

Another noteworthy aspect is the fact that the <u>case study could be strengthened through retrodiction</u> by confirming findings of the retroductive phase and adding rigor to the explanations. This would also have added a significant amount of work. A retrodictive assessment, following CR principles, would be an excellent opportunity for further research to bolster the transferability of this study's findings.

An additional conscious limitation of the work concerns <u>self-selection bias</u> of users of the parking system. The objective was to obtain current views and insights into the car parking experience, where people were interviewed on the street right after they left their parked cars. This prompted for a freshness of opinions regarding the process, which resulted in rich data about the system's drawbacks and potential unintended consequences. However, it also meant that all informants were current users of the application and population groups such as non-users who drive cars, former users, pedestrians, or other stakeholders were, by default, excluded from being interviewed. As an alternative, the researcher considered forming a focus group for an extended group interview, but such a gathering of individuals would have been subject to a different self-selection bias: people who have a special interest (or agenda) with regards to the Santander parking solution. The limitation was accounted for during expert interviews with city and University representatives where two of them (Informants C2 and U1) do not drive a car. While the expert interviews garnered primarily design-specific data, the views of these two non-driving residents were also considered in the analysis.

One likely impact on the study, and one that does not relate to a conscious design choice, was the general <u>disposition of users</u> pertaining to the shortcomings of the Santander Smart City program. As described in detail in Chapter 6 (Case Findings and Analysis), the city's parking availability picture poses a data quality issue that has eroded confidence over time in the system. This circumstance could have an impact on how people see the usefulness and value of the solution. Some informant's answers contained an undertone of general criticism that may have influenced other replies. If the case study had been conducted in a city where the Smart Parking program is seen as more of a success, the interviewee's answers may have been different, and the SBF may have produced insights that build upon the solution's strengths rather than attempt to overcome its existing weaknesses. Accounting for this circumstance required careful consideration by the researcher to apply the answer given solely to the question at hand.

Another unplanned situation in this research was brought on by the COVID-19 pandemic: Data gathering *in situ* took place during two distinct timeframes: October 2019 for expert interviews with designers, administrators, and operators, which also included other data gathering activities (document review, observations, and collection of photographic evidence). The interviews with users occurred two and a half years later in March 2022. The extended time between these two data collection points was caused by COVID-19 lockdowns and so the study took place during pre- and post-COVID times. The pandemic was a significant event that had the potential to skew answers to the researcher's questions. In addition, the overall traffic volume in March 2022, as the city 're-emerged' from COVID lockdowns, was still significantly lower than in October 2019. This has the potential implication that users in a 'near empty' city may not easily remember how things were when the parking system was overloaded. What lessened this disparity in time periods was the fact that all but two experts interviewed in October 2019 were drivers and also users of the parking system. Their views were captured as to how the system behaves in busy traffic conditions.

8.3 Future research

"When will the model not work? Will unforeseen events break it?" (Author)

This exploratory study is an approximate validation of the SBF in that it analytically resolved UCs arising from the interplay of the three sociotechnical domains: Human Agency, Material Agency, and Interpretive Schema. The study abductively crystallized these findings and retroductively validated the outcome. In following CR's framework of progression towards concretization and contextualization, the next phase could be a retrodictive assessment of the identified generative mechanisms. Such a future study would transpose theory exploration to theory testing and validate or adjust the, at present, identified generative mechanisms. The transferability argument of the SBF could be strengthened if future studies were conducted in different Smart Cities as far as their geographic, demographic, or historical setup is concerned. There are also various Smart City use cases that could be explored with the SBF: traffic management, public transportation, waste management, electricity/water/other utilities, etc.

These contextual variations in case studies may uncover UCs from findings that were expected but did not materialize. One potential future finding is expressed in the thought experiments in Chapter 4, which foresaw the high system security risk that is generally present in smartphone payment applications. Here, a system breach could expose credit card data and (private) parking location history with dates and times. Such a system breach was not found during data gathering and analysis in Santander.

There is an opportunity for future research to explore the use of the SBF beyond IoT in a Smart City, once IoT technology becomes more widely implemented and user experience data becomes available. Such an attempt at extending the SBF's generalizability could take place in a different sociotechnical setting within the realm of the IoT or even in other emergent and disruptive technologies (Big Data, Artificial Intelligence, etc.)

The SBF may be valuable when analysing conceptualization and implementation of other fast-changing technologies outside of a Smart City ecosystem. The SBF could conceivably be tested, and perhaps used, in other settings with complex human-technology interactions. An example would be automated weapon systems where the use of AI-based technology may have significant risks and merit the extensive analysis of the human, technology, interpretive schema interface.

8.4 Personal reflection

"If then, I were asked for the most important advice I could give, that which I considered to be the most useful to the men of our century, I should simply say: in the name of God, stop a moment, cease your work, look around you." — (Tolstoy, 2010: 157)

When looking back at the six years of this academic DBA adventure, preceded by two years of obtaining the MSc in Business and Management Research, two learnings tower over everything: the importance of structured research and an appreciation for the wealth of the complexities that arise when humans interact with technology (and vice versa).

I spent 35 years of my professional life in the private industry and the vast majority of this time in the United States and Canada. The difference of being a practitioner in fast-moving North American technology companies and doing academic research could not be starker. Business values the latest and greatest idea that ought to be presented in a short, catchy, novel, and bold pitch. Here, we tend to have 'the answer' first and attempt to support it with arguments of varying strengths that sometimes may only rely on pure instinct.

This is seriously at odds with academic concepts such as theoretical saturation or statistical validity. It is lightyears from the value system that academia espouses in the examination of what was written before, through a literature review, and that guides us towards the construction of a thesis based on data that is methodologically gathered and analysed. In academic reasoning, we set the stage with what is already known through literature and outline the gap by formulating research questions. Then, we propose a pathway to fill this gap according to how we see reality (ontology) and how we might obtain such knowledge (epistemology). After describing the knowledge acquisition process (methods), we embark on gathering such data, analyse it carefully, and place each piece into an emerging puzzle. We thus pass a number of waypoints to arrive at 'the answer' that lies in the distance.

Much revered is the American archetype of the entrepreneur who amassed a self-made fortune by following his nose. At the same time, we have all witnessed many 'great intuitions' that have turned into disasters. I believe that business practitioners have much to learn about the importance of structured research and how to augment business decision making with academic rigor.

It has been a privilege to learn the basics of business and management research during the MSc phase of my studies and apply them during this DBA part of the work. I am fascinated by Critical Realism that subscribes to the concept of an independent reality where we separate *the world* from what we *know about the world*. This opens the door to combining ontologies that are often seen separately – for example Realism and Relativism, as demonstrated in this thesis. There are many more paradigmatic assumptions, theories, methodologies, and methods that business practitioners can readily benefit from. I am inspired to look for ways to help bringing these academic concepts closer to my business colleagues.

At the beginning of this project, I started out with the goal of making Smart Cities better in the future and now realize that the (methodology) journey is infinitely better than the destination. This matches up with my second major learning of the complexities of human and technology interaction. As an IT professional, it is my aim to improve IT systems – by finding the causes of inhibitors of a 'perfect' human-technology interaction. Perhaps the most important learning is the realization that we have a way to cut up the 'block' of structure and agency into 'slices' in the quest to get to elusive generative mechanisms.

My objective in this 'improvement of IT systems' is for practitioners to use the SBF to avoid disconnects in circumstances where planning in fast-moving technology environments involves multiple parties. The SBF would be helpful in running through potential scenarios, much like in the thought experiments in Chapter 4, that include policy makers, business analysts, project managers, developers, users, and other stakeholders. The framework would aid in identifying where UCs might emerge from a combination of various pathways and to design solutions to avoid them. Through the systematic analysis of each arrow in the SBF, UCs can be anticipated before they manifest themselves downstream in the system development lifecycle. This enhances the process of building IT systems, whether through traditional waterfall or Agile development methodologies, and increases the speed and quality in creating solutions.

The framework could be applied in other fast-moving technology areas beyond the context of IoT in a Smart City, such as Big Data, Artificial Intelligence, Automated Weapon Systems, and other Machine-to-Machine interactions. It would be interesting to see how the framework can be used, and what results it would yield, with systems that do not exhibit a more balanced ‘tripartite relationship’ between Human Agency, Material Agency, and Interpretive Schema. These would be solutions branching into Artificial Intelligence, such as self-directing and self-learning systems, where the representation of the Human Agency circle of the Venn diagram is conceivably of less prominence. With this, the SBF could be continually ‘stress tested’ in a variety of use cases.

Appendix A – Suggested Improvement Actions

This appendix contains the alignment between an observed unintended consequence, the potential generative mechanism, and one or more suggested improvement actions. This is primarily based on how Santander has reacted to the problems experienced, but this could also be applied to other Smart Cities.

UC: Expected parking space unavailable

Problem: Once a driver arrives at a parking space, the space was previously flagged as ‘available’ when in fact it is now occupied.

Potential generative mechanism: Inaccurate capture of parking space availability due to negative affordances, time delays, or non-conforming usage (Trust Erosion).

Suggested improvement action(s): Utilize a technology that will capture the availability/non-availability of a parking space with a high degree of accuracy. In Santander’s case, the decision to implement a sensor-based system in 2012 caused a multitude of problems with the parking space availability signal, leading to severe trust erosion among users. Many cities have since implemented a camera-based system that is significantly more accurate in capturing the presence of vehicles (cars, motorcycles, etc.) and that accurately reads license plate information, which avoids user data entry errors.

UC: User frustrated by fine

Problem: In the absence of machine-readable technology, such as a camera-based system, the responsibility lies with the user to accurately enter data such as the license plate information. Simple data entry errors can lead to fines that are perceived as unfair by the user since s/he did in fact pay for parking, albeit the action was not correctly registered in the system.

Potential generative mechanism: Wrong data entry by user triggering an unexpected fine (Trust Erosion).

Suggested improvement action(s): When license plates are machine-readable, the issue of entering incorrect data is entirely avoided. In the absence of this technology, there should be additional validation mechanisms (user prompts) in the design so that such errors are minimized. In the case of Santander, these verification steps vastly reduced the data entry error rates.

UC: User outruns scanning vehicle to avoid fine

Problem: In Santander's case, the mere presence of an approaching scanning vehicle caused unsafe actions by drivers who either did not pay for parking or who assumed that they underpaid for the time that they remained in the parking spot.

Potential generative mechanism: Pre-emptive (unsafe) people actions prior to scanning vehicle arrival (Safety Issue).

Suggested improvement action(s): Conduct education for the public and sensitization/safety training for scanning vehicle operators. This has reduced the accident rate in Santander.

UC: Drop in scanning vehicle efficiency

Problem: Automated scanning vehicles make sense in traffic areas where they can operate with maximum flexibility. There is an inverted correlation between traffic volume and the efficiency of scanning vehicles.

Potential generative mechanism: Excessive traffic volume causing inefficiency of scanning vehicles (Profit Erosion).

Suggested improvement action(s): Monitor the throughput (number of license plates read per hour) of scanning vehicles. If this rate declines, consider replacing scanning vehicles with human patrollers and again compare the efficiency rate. This may require a dynamic reallocation between scanning vehicles and human patrollers since traffic volume in a street can be fluid.

UC: User non-involvement fostered resentment

Problem: Santander experienced a high degree of resistance and non-acceptance with the new Smart Parking system. The project design was largely completed by the core project team.

Potential generative mechanism: Insufficient (early) user involvement by the project team (Trust Erosion).

Suggested improvement action(s): Santander utilized focus groups and other community outreach venues, such as their Smart Santander Visitor Centre, to capture a more wide-ranging input from residents. The suggestion here is to do this at the beginning of the project where the community at-large feels a sense of ownership.

UC: Disruption of routine causes frustration

Problem: The city's residents were not sufficiently prepared for the disruption that was caused by the system implementation. Most of this disruption was due to installing sensors under the road pavement with its associated street closures, noise, and a negative impact on adjacent restaurants and business.

Potential generative mechanism: Inadequate change management (Trust Erosion).

Suggested improvement action(s): Institute a change/management program that clearly communicates the benefits of the new system to all parties involved. User frustration can be minimized once people understand the value of the new system and what the community will gain from its implementation.

UC: Unrelated fee increase caused user resentment

Problem: The Smart Parking system go-live coincided with an unrelated parking fee increase that was not coordinated. The interviews suggested that residents incorrectly attached the higher fee to the new system.

Potential generative mechanism: Conflation of unrelated events (Trust Erosion).

Suggested improvement action(s): This problem could have been proactively addressed during up-front change/management initiatives. As part of the roll-out, simultaneous changes should be minimized to avoid ‘change fatigue’ among citizens as well as incorrect associations among unrelated events.

UC: Anonymity of system is conducive to cheating

Problem: Once human patrol officers were replaced with automated scanning vehicles, the city experienced a rise in parking non-payment – a ‘free rider syndrome’. This was subsequently attributed to the anonymity of scanning vehicles versus human patrol officers. Once the city added patrol officers back (as part of counteracting the unintended consequence described in Section 6.4.1.5), the non-payment of parking declined.

Potential generative mechanism: Increases of non-payment due to non-supervised automation (Profit Erosion).

Suggested improvement action(s): Educate residents by appealing to their ‘sense of fairness’ in addition to having some degree of human presence with patrol officers.

UC: General parking space unavailability

Problem: Santander has struggled in keeping a certain number of parking spaces reserved for residents as opposed to visitors. What exacerbates the problem is that the city experiences a massive influx of tourists in the summer months.

Potential generative mechanism: Seasonality affecting space requirements and leading to shortages (Trust Erosion).

Suggested improvement action(s): Establish routines to more frequently assess the division between resident and visitor parking spaces. In Santander’s case, the city switched from a yearly allocation to a quarterly allocation method that provided more planning granularity for the busy summer months.

UC: Users unfairly pay too little or too much for parking

Problem: With the introduction of the new parking solution, the city did not revise its parking zoning plan that allocates specific streets to a parking zone. Over time, the parking practices changed, and several zones now cover respective areas that have varying parking volumes.

Potential generative mechanism: Mismatches between price and parking volume due to dynamic zone pricing (Trust Erosion).

Suggested improvement action(s): Based on the UC experienced in Santander, Smart Cities should frequently assess the mapping of streets into parking zones. The test should be that all streets within a zone have a largely homogenous parking volume so that dynamic pricing rules, per zone, support the traffic distribution among zones.

UC: Service provider's proposals are unrealistic

Problem: Santander experienced a problem where Government subsidies are given to innovative ideas that fulfil the requirements of subsidies, but not necessarily the required true innovation needed for the city's infrastructure. At that time, there was an inadequate selection process in place for innovation projects.

Potential generative mechanism: Skewed innovation towards subsidies instead of true innovation (Trust Erosion).

Suggested improvement action(s): Cities should ensure that a Governance process is in place that supports a wide range of topics and where initiatives are prioritized based on true needs. In addition to city officials on a Governance committee, there should be representation from all stakeholders. These would include commercial delegates (shop owners, restaurateurs, taxi drivers), associations and interest groups, users, community activists, service providers, technology providers, and other technology integrators or enablers.

UC: Project cost exceeds estimate

Problem: While this can occur in many technology projects, the biggest cost overrun that Santander experienced was caused by the underground installation of sensors.

Potential generative mechanism: Exceeded cost estimates due to underground sensor installation (Profit Erosion).

Suggested improvement action(s): Utilize standard project estimation techniques by identifying upper and lower boundaries, probabilities of high/low numbers, planning for buffers, etc.

UC: Unscheduled roadwork decreases profit

Problem: Every parking space that is not usable minimizes the profit potential of the parking service provider. Santander originally did not plan out road closures well, which created financial disadvantages for Dornier, the parking service provider.

Potential generative mechanism: Unavailability of parking spaces due to road maintenance (Profit Erosion).

Suggested improvement action(s): Minimize road closures by 'bundling' road maintenance work together and conducting repairs during low-volume parking times, for example at night or on public holidays.

UC: Smaller pool of potential service providers

Problem: Service providers that are lacking the technological know-how are not able to comply with the technical deliverables that are required when servicing a Smart City. This has reduced the pool of potential vendors.

Potential generative mechanism: Lack of technical knowledge at service provider preventing competition (Profit Erosion).

Suggested improvement action(s): Cities should provide technical assistance to service providers who need this help. This could be done through additional documentation or FAQ documents. In the case of Santander, the Program Management Office appointed a team of technical specialists who would actively support service providers with the technological parts of the service offering.

UC: Two-hour parking maximum alters behaviour

Problem: Santander has chosen a two-hour parking limit during peak-times. While this makes sense when parking spaces are constraint, it is an unfitting rule when sufficient parking spaces are available. Users are therefore relocating their cars to a nearby parking spot after two hours have passed to avoid a fine.

Potential generative mechanism: Disruption due to car relocations (post two-hour limit in peak times) (Trust Erosion).

Suggested improvement action(s): Cities should consider suspending such a rule when sufficient parking spaces are available. This could be accomplished through a feedback mechanism in the system. When parking volume in the area is low, the two-hour limit should not be applied. This could be dynamically handled, for example through a message that the user receives on his/her smart phone with an alert that the car relocation is not required.

Conversely, if traffic volume is high, the message could indicate that the allotted parking time is about to expire.

UC: Delayed compliance checks conducive to rule breaking

Problem: This is related to the finding described in Section 6.4.1.5 where the absence of a visible control mechanism impacts the user's behaviour as it relates to parking payments. It was observed that a decreased frequency of scanning vehicle drive-throughs corresponds with an increase in not paying for parking.

Potential generative mechanism: Increases of non-payment due to decreased patrol frequency (Profit Erosion).

Suggested improvement action(s): Here, like in Section 6.4.1.5, Santander's answer was an appeal to people's 'sense of fairness'. It is conceivable for a city to increase the frequency of control vehicles. In Santander's case, this turned out to be cost prohibitive, since the anticipated benefit would not outweigh the increase in cost of running more scanning vehicles. However, this cost/benefit balance may be different in other cities.

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