Climate and construction delays: case study in Chile

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Abstract

Purpose – Construction projects usually suffer delays, and the causes of these delays and its cost overruns have been widely discussed, the weather being one of the most recurrent. The purpose of this paper is to analyze the influence of climate on standard construction work activities through a case study.

Design/methodology/approach – By studying the extent at which some weather variables impede outdoor work from being effectively executed, new maps and tables for planning for delays are presented. In addition, a real case regarding the construction of several bridges in southern Chile is analyzed.

Findings – Few studies have thoroughly addressed the influences of major climatic agents on the most common outdoor construction activities. The method detailed here provides a first approximation for construction planners to assess to what extent construction productivity will be influenced by the climate.

Research limitations/implications – Although this study was performed in Chile, the simplified method proposed is entirely transferable to any other country, however, other weather or combinations of weather variables could be needed in other environments or countries.

Practical implications – The implications will help reducing the negative social, economic and environmental outcomes that usually emerge from project delays.

Originality/value – Climatic data were processed using extremely simple calculations to create a series of quantitative maps and tables that would be useful for any construction planner to decide the best moment of the year to start a project and, if possible, where to build it.

Keywords Planning, Construction management, Productivity rate, Data analysis, Decision support systems, Construction works

Paper type Case study

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Introduction

The construction industry serves as a fundamental pillar for the economic and social development of a country (Ballesteros-Pérez *et al.*, 2010) and is usually reflected by its sensible contribution to the gross domestic product (GDP). In Chile, the contributions of the construction sector to the GDP represented 7.7 percent in 2012, corresponding to 26,400 million USD in investment for the Chilean economy (Cámara Chilena de la Construcción, 2013). Nevertheless, despite the strong growth that Chile has shown in recent years, the contributions of the Chilean construction sector to the GDP are below average when compared with the international trend for highly developed economies of approximately 10 percent. This contribution corresponds to approximately 8.7 billion USD globally according to the International Monetary Fund (2014) or 9.7 billion USD according to the World Bank (2013).

However, despite these impressive figures, construction projects usually suffer delays, and a significant number of high profile, international projects fail to be completed on-time and on-budget (Hans *et al.*, 2007; Vanhoucke, 2012).

The causes of these delays and cost overruns have been widely discussed in the literature. In addition, recent research efforts have focussed on quantitatively evaluating the impacts of delays (González *et al.*, 2014) and process variability (Poshdar *et al.*, 2014) because both aspects can negatively affect performance and disrupt production. A McKinsey study reported in *Business Week* indicated that a project that is on time but 50 percent over-budget will only earn 4 percent less than the same project if it is finished on budget. In contrast, the same study stated that a project that is within budget but with a six-month delay will earn 33 percent less than the very same project when it is completed on-time (Port *et al.*, 1990).

In Chile, a study focussing on national construction productivity indicated that problems related to activity planning and co-ordination accounted for 36 percent of construction project delays, which occupied the first position among other causes, such as work methodology (21 percent), lack of supervision (17 percent) and material supply (11 percent) (Corporación de Desarrollo Tecnológico, 2011).

From all of the claims above, a construction manager can deduce that each extra month needed to finish a construction project would result in an income loss of approximately 5.5 percent, a figure that is not negligible even when it is roughly calculated.

Hence, the construction industry is important for the economy. However, a large number of construction projects are finished late and generate lower efficiencies that are eventually manifested as budget overruns, unnecessary waste of natural and material resources (Ballesteros-Pérez *et al.*, 2010; Faniran and Caban, 1998), greater greenhouse gas and air pollutant emissions (Ahn and Lee, 2013), a greater number of claims (Kumaraswamy, 1997; Trauner *et al.*, 2009), and a larger number of litigation cases (Xi *et al.*, 2005). As mentioned above, if project planning and coordination of construction activities cause 36 percent of the delays, additional approaches that address these factors are necessary.

In this paper, a new analysis regarding the influences of climatic on construction project delays is presented. As shown later, weather conditions can significantly influence the performance of construction activities. However, this influence varies widely (as expected) because it depends on the exact location of the project (Jang *et al.*, 2008; Migliaccio *et al.*, 2013) and on the particular moment in time during which the work is carried out (Othman *et al.*, 2006). To measure the extent of the influences of weather on construction work, a case study was developed in Chile using national climatic data from the last ten years to determine which, when and how construction activities are influenced.

Climatic data were processed using extremely simple calculations to create a series of quantitative maps and tables that would be useful for any construction planner or procurer to decide the best time to build or to provide a more accurate estimation of the final project delays if a project must be built at a certain location during a fixed calendar interval. The implications of this study will therefore help to reduce the negative social, economic and environmental outcomes that usually emerge from project delays (Hamzah *et al.*, 2011).

Literature review

Construction projects consist of numerous technological operations, most of which can be rearranged in multiple ways whenever their technological precedences are observed (Vanhoucke, 2011). Breaking down operations into activities will define the project work breakdown structure (WBS). This WBS will most likely influence the results of later schedule optimization (Dytczak *et al.*, 2013; Tommelein, 1998).

Hence, the susceptibility of construction processes to adverse weather conditions may result in appreciable time (Choo *et al.*, 1999) and financial losses (Alaghbari *et al.*, 2007; Pewdum *et al.*, 2009). Thus, unexpected adverse weather conditions can slow down or stop work (Dytczak *et al.*, 2013; Mahamid, 2013).

The statements "climate conditions are very difficult to predict and plan for in advance" (Sun and Meng, 2009), "weather predictions are plagued by uncertainty" (Jones, 2001) or even "Delays as a result of weather conditions are […] significant risk factors in the contract delivery process, […] but construction managers are often unable to reliably predict delays as a result of them" (Thorpe and Karan, 2008) are familiar to many contractors. Therefore, it should not seem strange that climate and weather conditions are often reported as one of the main causes of project delays and unscheduled changes (El-Rayes and Moselhi, 2001; Orangi *et al.*, 2011) and serve as a pretext (sometimes justified and sometimes not) for contractor claims (Yogeswaran *et al.*, 1998).

Thus, a recent paper by Nguyen *et al.* (2010) classified seven factors that usually cause disputes between the contractor and the contracting authority in projects that suffer delays due to adverse weather conditions. These seven factors include the definition of normal weather, weather thresholds, the type of work, the number of lingering days, criteria for lost days, the lost days equivalent due to lost productivity and the number of work days lost vs the number of calendar days lost. However, the same authors claimed that "future research may provide an appropriate mechanism for analyzing equivalent lost days to account for lost productivity" (Nguyen *et al.*, 2010), which justifies the aim of this paper.

In contrast, the climatic agents that are most commonly cited as sources of significant project deviations from the baseline schedule include extreme cold, precipitation, heat and wind (Büdel, 2006; Choi and Hartley, 1996; David *et al.*, 2010; Rogalska *et al.*, 2006; Shahin *et al.*, 2011, 2014). Paradoxically, these climatic agents are continuously connected to other resource-intensive activities, such as agriculture (Block *et al.*, 2008; Fowler and Kilsby, 2007; Jones and Thornton, 2013) and shipbuilding (Jang *et al.*, 2008), or are analyzed when assessing zone vulnerability (Ekström *et al.*, 2007; Persson *et al.*, 2007), the resilience of construction to natural disasters (Bosher, 2014), or future climate change (Guan, 2009; Hallegatte, 2009; Nik *et al.*, 2012). However, the effects of climatic agents on project delays are generally left out of mainstream climate and construction research.

Likewise, meteorologists generally view weather forecasting as a description of nature rather than as an input to decision process (Regnier, 2008). Consequently, research regarding the application of methods that cross climatic variables and construction activity performance are scarce, with only a few exceptions. For example, El-Rayes and Moselhi (2001) developed a decision support system for quantifying the impacts of rainfall on productivity and the duration of common highway construction operations. In addition, Shahin *et al.* (2011, 2014) created a framework that allowed users to simulate and plan pipeline construction activities under extremely low temperatures. Marzouk and Hamdy (2013) quantified the productivity losses and the effects of weather on formwork shuttering and removal operations by using analytical fuzzy and system dynamic models.

Additionally, apart from other studies that semi-quantitatively consider the effects of weather on weather-sensitive construction activities (e.g. Jang *et al.*, 2008; Thorpe and Karan, 2008), only one study led by Apipattanavis *et al.* (2010) other than our work has focussed on developing a consistent method for estimating a reasonable number of non-work days in highway construction projects due to weather-related events, in this case using a stochastic weather generator.

To our knowledge, the first legislation and codes of practice were introduced in 1964 when the Ministry of Public Works in Spain published "Climatic data for highways" to help highway construction managers accurately plan for the extension of some construction work packages due to adverse weather (Ministerio de Obras Públicas (MOP), 1964). Several years later, the American Transportation Research Board released a publication regarding the effects of weather on highway construction (National Cooperative Highway Research Program, 1978). Following this 1978 publication, several other public agencies developed internal procedures to account for the influences of weather in some way. Nevertheless, Hinze and Couey (1989) conducted a survey report several years later that highlighted the major differences and observed low consistency among the methods that US Public Agencies use to handle weather issues in contracts. Unfortunately, this lack of consistency remains valid today, at least regarding the construction industry.

Finally, many studies have related the influences of climate to construction activities in reverse (i.e. modeling how several aspects of construction projects affect regional climates: Rummukainen, 2010 or global climate change: White *et al.*, 2010). However, the results of these studies do not provide useful insights for this study.

Research method

From the literature review above, it is clear that starting, continuing and stopping on site construction activities depend on weather conditions; therefore, weather information should be considered as early as the planning phase (Jang *et al.*, 2008). Hence, this method and the major contribution of this research aim to calculate how long each construction activity may be extended as a function of likely future climatic events by generating new maps depicting geographical and time variation of decrements on production rates. This calculation depends on which construction activity will be carried out as well as when and where that activity will be performed.

To fulfill this task, two primary issues must be considered, the retrieval of climatic data and how climatic events will actually affect the construction activities.

Because this study was conducted in Chile, climatic information was obtained from the Chilean Meteorological Directorate, which publishes an annual climatic directory (freely available at http://164.77.222.61/climatologia/). Specifically, this analysis took advantage of the annual climatic directories from 2003 to 2012 (Dirección Meteorológica de Chile, 2012) (i.e. a ten-year time span). By comparing these data with data from prior studies with time periods of five (White *et al.*, 2010) to 30 years (Jang *et al.*, 2008), the chosen time series duration was considered adequate. In addition, the time series allowed for a sufficient volume of climatic data from the more recently installed Chilean weather stations.

Regarding the degree by which construction activities are influenced by weather conditions, this study mainly focussed on construction work activities that partially (such as buildings) or entirely (such as highways, pipelines and bridges) occurred outdoors.

Thus, when analyzing climatic variables in relation to construction activities, the boundaries regarding the intensities of a given climatic event that actually prevent a particular construction activity from being performed becomes very vague. For example, a precipitation event of 10 mm may be enough to stop some earthmoving projects if the soil is clayey; however, if the soil is sandy or contains significant amounts of gravel, even 20 mm of rainfall would be insignificant. Other factors, such as how well the drainage system functions, the rainfall intensity, the technical features of the machinery that are used for moving earth and solar radiation could influence the exact level of precipitation that would prevent work for a certain period.

Therefore, it is nearly impossible to set exact and unmovable climatic thresholds above which construction activities cannot be performed because they depend on a combination of other collateral climatic events and many other factors, most of which are unknown or undecided before the work begins.

However, this fact should not prevent us from trying to improve the current situation in which weather is rarely considered in construction projects until adverse weather conditions arise. Thus, this study aims to describe general thresholds and combinations of climatic factors that are considered as deterrents for the most common types of outdoor construction.

As mentioned above, this study used the Chilean annual climatic directories in which climatic events are partially processed and summarized as many other climatic directories around the world (i.e. they contain little raw climatic data). However, the use of these data is advantageous for non-experts and for the current method because it considers the number of eligible climatic variables as a handful of variables that are actually useful and with data and frequencies that are nearly ready for immediate use.

Among the climatic variables described in the Chilean annual directories the following information exists: records of monthly average and daily extreme temperatures; relative humidity; total monthly sun hours; detailed monthly and daily atmospheric pressure measurements; monthly wind frequency, dominant direction and average speed; monthly cloud cover; and monthly total and maximum daily precipitation. All of this data is available from every Chilean weather station in current use during the previous year. However, out of all these variables only four were considered of interest and were differentiated by month from January to December as follows:

- number of days with temperatures below 0°C (at 8:00 am);
- number of days with precipitation above 1 mm;
- number of days with precipitation above 10 mm; and
- number of registers with wind speed above 9 knots.

In this case, the "number of days" comprises the sum of measurements found during the analysis interval (generally ten years, and three years for the newer weather stations). Namely, the four variables as well as their threshold magnitudes set above, unlike other weather variables registered, were chosen for their close and straightforward relationship with some undesirable physical effects on major civil construction activities such as earthwork, formwork, concrete, pavement and steelwork, as justified later. Although the combination of chosen climatic variables could be enriched by other weather information already present in the annual climatic directories, the aim of this study is to provide the simplest method to allow for quick calculations at the layman level.

Furthermore, only 24 out of the 32 Chilean weather stations that are currently operating were used for this study. Eight stations were not considered because they were not on continental land (Chilean Antarctica and Easter Island) and/or did not have at least three years of climatological data, which is necessary for providing reliable information for forecasting.

Thus, with the counting of days obtained from and for these 24 weather stations, the following "raw climatic coefficients" (C_t, C_{p1}, C_{p10} and C_w) were obtained for 12 months of the year and for the ten years of analysis.

Temperature coefficient:

$$C_t = 1 - \frac{Number\ of\ days\ with\ temperatures\ below\ 0^{\circ}C}{Number\ of\ monthly\ days \times Years\ of\ analysis} \tag{1}$$

1 mm-precipitation coefficient:

$$C_{p1} = 1 - \frac{Number\ of\ days\ with\ precipitation\ above\ 1\ mm}{Number\ of\ monthly\ days \times Years\ of\ analysis} \tag{2}$$

10 mm-precipitation coefficient:

$$C_{p10} = 1 - \frac{Number\ of\ days\ with\ precipitation\ above\ 10\ mm}{Number\ of\ monthly\ days \times Years\ of\ analysis} \tag{3}$$

Wind speed coefficient:

$$C_w = 1 - \frac{Number\ of\ days\ with\ winds\ speed\ above\ 1\ mm}{3 \times Number\ of\ monthly\ days \times Years\ of\ analysis} \tag{4}$$

In the expressions above, the closer each coefficient is to 1, the less likely the occurrence the same weather phenomenon on that month will be, on average. This means that it is consequently less likely that a weather-sensitive construction activity might suffer a delay. Equation (4) is divided by 3 because, in Chile, wind speed measurements are representative of an eight-hour period, that is, are taken thrice a day, unlike variables used in Equations (1)-(3), which are representative of a 24-hour interval.

However, these raw climatic coefficients are not completely useful unless they are combined to reflect how a single or set of weather events can actually prevent construction activities from being performed. Thus, five groups of major construction activities were selected for this study and their "climatic reduction coefficients" (*E*, *F*, *C*, *P* and *S*) are shown below.

Earthworks (*E*): earthmoving works, such as excavations and landfilling, are highly influenced by rainfall (Apipattanavis *et al.*, 2010) (rainfall hinders performance and increases soil humidity when compacting) and frozen soils (Shahin *et al.*, 2011, 2014). Frozen soils are generally found in the Southern regions of Chile (Antarctica), where few people live. Thus, these soils were not considered in this analysis. However, snow can also influence the productivity of earthworks to a minor extent. Nevertheless, snowfall in Chile is registered as precipitation and was counted as rainfall. The earthworks climatic reduction coefficient was calculated by considering all of these issues as follows:

$$E = C_{p10} \tag{5}$$

Formworks (*F*): formwork shuttering and removal operations were recently studied in detail by Marzouk and Hamdy (2013), including variables like the level of rainfall and temperature. However, a simpler approach was preferred here. Specifically, a wind speed of 9 knots (equivalent to 16.78 km/h) provides enough momentum to tilt a standard 28 kg/m^2 formwork by 30°. Thus, this wind speed was considered as a reasonable safety threshold and was chosen as the wind speed critical value. Other similar thresholds found in the literature include the wind speed above which it is forbidden to operate a crane in accordance with Chilean construction legislation (Norma Chilena Oficial, 1999), which is 64 km/h or approximately 36 knots). However, it is important to remember that a crane is an element that is generally anchored; thus, its resistance to falling is much greater. Thus, the formworks climatic reduction coefficient was calculated as follows:

$$F = C_w \tag{6}$$

Concrete (*C*): several climatic events can deteriorate a constructive element when concrete is being poured or is curing. However, most of these events can be avoided by using extra measures during the execution phase, such as covering the concrete with plastic sheets during strong wind or mixing additives with the concrete. However, two different climatic events were considered as influential enough to account for a loss of productivity: rainfall above 10 mm and temperatures below 0°C.

According to the American Concrete Institute (1985), concrete expands and creates micro-fractures when water freezes (below 0°C), which accelerates short-term deterioration. In contrast, precipitation produces compressive decreases in strength as a function of too much additional water. Of course, the quantity of extra rainwater depends on the ratio of the surface to the thickness of the concrete. On average, 1 m^3 of concrete requires approximately 130 liters of water. Because 10 mm of rainfall adds 10 liters/m^2, this generally means that there is enough water to reduce the compressive strength of concrete by at least 10 percent in most cases (according to Jimenez and Morán, 2001). Consequently, the concrete climatic reduction coefficient was calculated by combining two raw climatic coefficients as follows:

$$C = C_t \times C_{p10} \tag{7}$$

Pavements (*P*): pavement is defined as any surface operation that requires asphaltic mixtures. According to the highway construction manual from the Chilean Ministry of Public Works (Ministerio de Obras Públicas (MOP). Dirección de Vialidad de Chile, 2008), no asphalt mix can be spread when it is raining because asphalts consist of organic compounds that are mainly composed of hydrocarbons that are generally oxidized in the presence of water. Furthermore, when asphalt mixes are hot and contact water, the temperature difference creates a foam that modifies the chemical structure and decreases the future durability and permeability (MOP, 1964).

In contrast, temperatures below 0°C increase the viscosity too quickly, which complicates handling the mixture and the spreading and compacting processes. Thus, the pavements climatic reduction coefficient was calculated as follows:

$$P = C_t \times C_{p1} \quad (8)$$

Steelworks (*S*): steelworks include all operations that are aimed at erecting a steel structure and do not consider the steel elements for reinforcing concrete that are only affected by electric storms (which rarely occur in Chile). Therefore, the major risks associated with steelworks address handling and welding heavy metallic elements. Consequently, wind is considered as detrimental for erecting any steel structure. Furthermore, Thomas *et al.* (1999) determined that snow generated 41 percent of productivity loss in steelworks. However, as previously mentioned, snow is considered in the precipitation coefficients. Consequently, the steelworks climatic reduction coefficient is obtained as follows:

$$S = C_{p10} \times C_w \quad (9)$$

Having explained the main coefficient calculations, Table I illustrates how the main climatic calculations were performed for the Puerto Montt Chilean weather station (other stations are not shown due to a lack of space).

Obviously, all these "climatic reduction coefficients" varied from 0 to 1. If a coefficient equals 1, the activity will not suffer from delays due to climate during that month. In contrast, lower coefficients correspond with lower productivity during the execution phase. Indeed, the actual performance activity will be calculated as the performance measured with optimum weather conditions multiplied by the respective "climatic reduction coefficient."

As shown in Table I, climatic coefficient calculations are simple and straightforward. In fact, these calculations were performed at the 24 weather stations mentioned above in Chile. After calculating the climatic reduction coefficient isocurves using the SURFER v.11 software (Golden Software, 2013), the following maps shown in Figure 1 were obtained. These maps highlight the position of the main Chilean cities. However, not all of the cities hosted a weather station; thus, Figure 2 summarizes the respective coefficient values of these cities.

Finally, steelworks climatic reduction coefficients have not been included due to space restrictions and because they will not be used in the latter case studies. In addition, Figure 1 only shows the "annual" (average) climatic reduction coefficients because the monthly climatic maps would require another 48 maps.

Now that the method has been detailed, the next logical step is to deploy secondary analyses. First, a real case will be detailed by applying the calculations for the same climatic reduction coefficients. Then, a more general case study will be projected to prove how the same construction work can be realized with a very different time span depending on when and where it is performed.

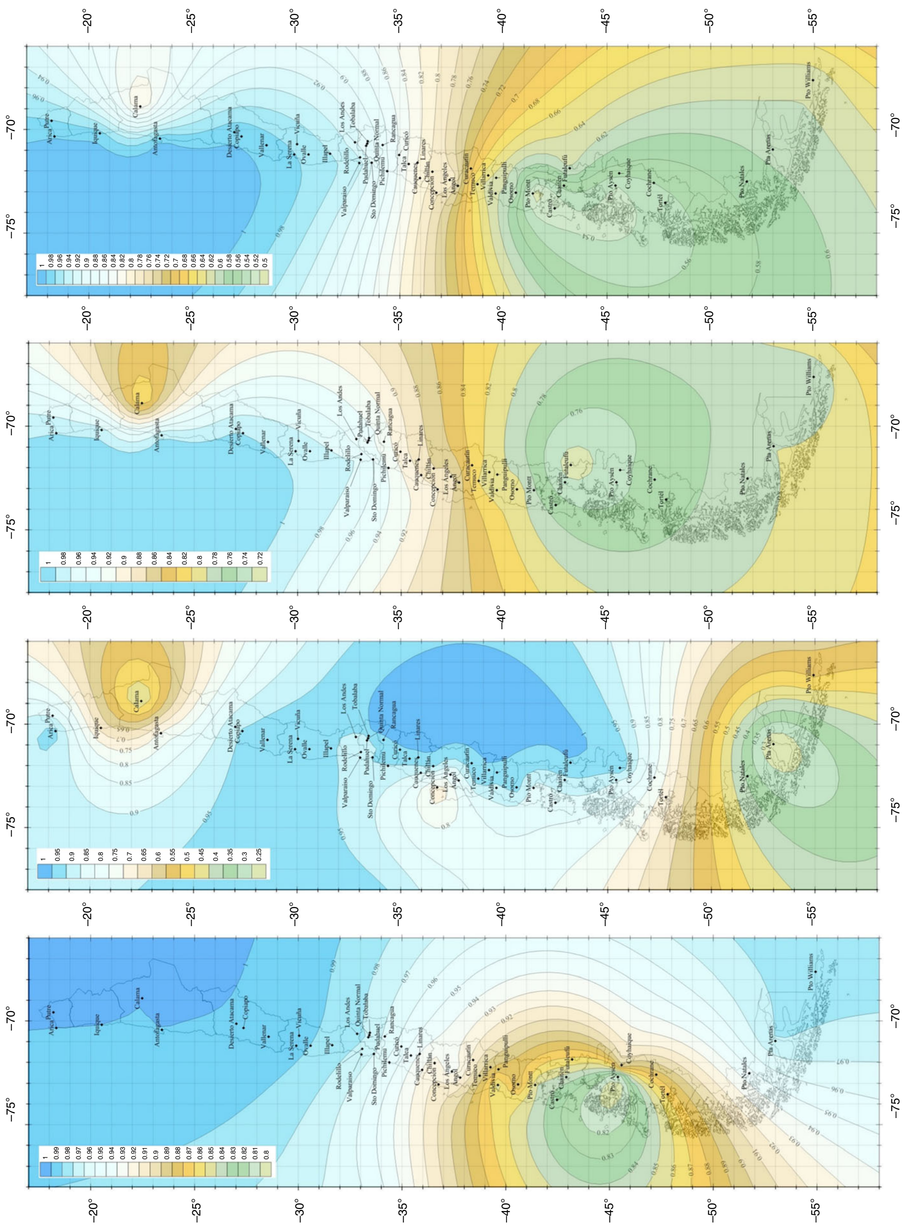
Case study

The real case study applying the method shown above includes the construction of six short bridges by the same contractor in 2011 and 2012. The bridges were built in the cities of Puerto Montt and Osorno in Southern Chile, and all of them shared very similar

Table I. Example of climatic reduction coefficient calculations from a weather station

	Puerto Montt weather station												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Monthly days	31	28**	31	30	31	30	31	31	30	31	30	31	
Years of analysis	10	10	10	10	10	10	10	10	10	10	10	10	
Days with temperature $\leqslant 0°C$	0	0	1	6	48	51	73	73	49	14	0	3	
Days with precipitation $\geqslant 1$ mm	94	80	123	136	148	197	186	183	147	157	104	134	
Days with precipitation $\geqslant 10$ mm	26	20	39	41	62	90	64	76	35	32	30	36	
Days with winds $\geqslant 9$ Knots*	50	39	14	59	163	322	198	277	89	83	64	68	
Raw climatic coefficient calculations													
Temperature coefficient (Ct)	1.00	1.00	1.00	0.98	0.85	0.83	0.76	0.76	0.84	0.95	1.00	0.99	
1 mm-precipitation coefficient ($Cp1$)	0.70	0.71	0.60	0.55	0.52	0.34	0.40	0.41	0.51	0.49	0.65	0.57	
10 mm-precipitation coefficient ($Cp10$)	0.92	0.93	0.87	0.86	0.80	0.70	0.79	0.75	0.88	0.90	0.90	0.88	
Wind speed coefficient (Cw)	0.95	0.95	0.98	0.93	0.82	0.64	0.79	0.70	0.90	0.91	0.93	0.93	
Climatic reduction coefficient calculations													Annual
Earthworks ($E = Cp10$)	0.92	0.93	0.87	0.86	0.80	0.70	0.79	0.75	0.88	0.90	0.90	0.88	0.85
Formworks ($F = Cw$)	0.95	0.95	0.98	0.93	0.82	0.64	0.79	0.70	0.90	0.91	0.93	0.93	0.87
Concrete ($C = Ct \times Cp10$)	0.92	0.93	0.87	0.85	0.68	0.58	0.61	0.58	0.74	0.86	0.90	0.88	0.78
Pavements ($P = Ct \times Cp1$)	0.70	0.71	0.60	0.54	0.44	0.28	0.31	0.31	0.43	0.47	0.65	0.56	0.50
Steelworks ($S = Cp10 \times Cw$)	0.87	0.89	0.86	0.81	0.66	0.45	0.62	0.53	0.80	0.82	0.84	0.82	0.75

Notes: *In Chile, wind speed is measured three times each day; thus, the wind speed coefficient must be divided by 3; **February only had 29 days in 2004, 2008, and 2012. However, the error generated by this simplification is always less than 1 percent



Note: From left to right: earthworks, formworks, concrete and pavements

Figure 1. Annual climatic reduction coefficient maps

constructive elements that allowed for relative comparisons once their dimensions were homogenized.

Table II summarizes the main construction aspects of these bridges and is divided into three sub-tables. The two upper tables depict the construction activities by rows,

Location (Chile)	Earthworks (E)													Formworks (F)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Putre	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.79	0.83	0.87	0.87	0.95	0.95	0.95	0.95	0.95	0.95	0.93	0.91	0.89
Arica	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.89	0.90	0.97	0.96	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.97	0.97
Iquique	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.43	0.21	0.48	0.64	0.82	0.90	0.87	0.87	0.77	0.79	0.74	0.60	0.68
Calama	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.19	0.19	0.34	0.43	0.58	0.62	0.57	0.55	0.45	0.43	0.53	0.39	0.44
Antofagasta	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.78	0.73	0.79	0.99	0.99	0.98	0.96	0.91	0.61	0.43	0.51	0.53	0.77
Atacama dessert	1.00	1.00	1.00	1.00	0.99	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.91	0.98	0.99	1.00	0.98	0.96	0.89	0.91	0.93	1.00	0.82	0.94
Copiapo	1.00	1.00	1.00	1.00	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.93	0.96	0.99	1.00	0.97	0.96	0.91	0.92	0.93	1.00	0.86	0.95
Vallenar	1.00	1.00	1.00	1.00	0.99	0.98	0.98	0.99	1.00	1.00	1.00	1.00	0.99	0.97	0.96	0.97	1.00	1.00	0.99	0.97	0.95	0.96	0.96	1.00	0.92	0.97
La Serena	1.00	1.00	1.00	1.00	0.99	0.97	0.97	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vicuña	1.00	1.00	1.00	1.00	0.98	0.97	0.97	0.98	1.00	0.99	1.00	1.00	0.99	0.98	0.99	1.00	0.98	0.98	0.97	0.97	0.99	0.98	0.97	1.00	0.97	0.99
Ovalle	1.00	1.00	1.00	1.00	0.98	0.96	0.97	0.98	1.00	0.99	1.00	1.00	0.99	0.96	0.97	1.00	0.99	0.98	0.98	0.97	0.98	0.97	0.97	0.98	0.96	0.98
Illapel	1.00	1.00	1.00	0.99	0.98	0.94	0.97	0.96	0.99	0.99	1.00	1.00	0.99	0.91	0.94	0.98	0.98	0.97	0.97	0.97	0.97	0.96	0.96	0.95	0.90	0.96
Los Andes	1.00	1.00	0.99	0.99	0.98	0.92	0.96	0.95	0.99	0.99	0.99	1.00	0.98	0.85	0.86	0.99	0.96	0.98	0.98	0.98	0.97	0.97	0.97	0.93	0.80	0.94
Valparaíso	1.00	1.00	0.99	0.99	0.97	0.91	0.95	0.93	0.99	0.98	0.99	1.00	0.97	0.85	0.87	0.96	0.97	0.96	0.97	0.96	0.95	0.94	0.93	0.96	0.85	0.93
Rodelillo	1.00	1.00	1.00	0.99	0.98	0.89	0.97	0.94	0.99	0.98	0.99	0.99	0.98	0.84	0.87	0.99	0.94	0.96	0.99	0.94	0.94	0.92	0.92	0.94	0.84	0.92
Santo Domingo	1.00	1.00	1.00	0.99	0.96	0.88	0.93	0.93	0.98	0.99	1.00	1.00	0.97	0.86	0.95	0.94	0.98	0.99	1.00	1.00	0.98	0.97	0.91	0.94	0.93	0.95
Pudahuel	1.00	1.00	1.00	0.99	0.97	0.93	0.95	0.95	1.00	0.99	0.99	1.00	0.98	0.61	0.70	0.97	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.71	0.50	0.87
Quinta Normal	1.00	1.00	0.99	0.99	0.95	0.92	0.95	0.94	0.99	0.99	0.99	1.00	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tobalaba	1.00	1.00	1.00	0.99	0.97	0.92	0.95	0.94	0.99	0.99	0.99	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	1.00
Rancagua	0.99	0.99	0.99	0.98	0.95	0.88	0.94	0.92	0.98	0.98	0.99	1.00	0.97	0.98	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.98	0.96	0.99
Pichilemu	0.99	0.99	0.99	0.98	0.94	0.84	0.91	0.90	0.97	0.97	0.99	1.00	0.96	0.87	0.93	0.95	0.97	0.96	0.96	0.95	0.96	0.96	0.92	0.93	0.90	0.95
Curicó	0.99	1.00	0.99	0.98	0.93	0.84	0.93	0.90	0.98	0.97	0.99	1.00	0.96	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.99	1.00	0.97	0.99
Talca	0.99	0.99	0.99	0.97	0.92	0.82	0.89	0.88	0.98	0.96	0.98	0.99	0.95	0.96	0.97	0.98	0.98	0.97	0.96	0.96	0.96	0.97	0.96	0.97	0.96	0.97
Linares	0.99	0.99	0.99	0.96	0.91	0.81	0.87	0.88	0.96	0.96	0.98	0.98	0.94	1.00	0.99	0.98	0.98	0.97	0.96	0.96	0.97	0.98	0.98	0.99	0.97	0.98
Cauquenes	0.99	0.99	0.99	0.96	0.90	0.80	0.84	0.86	0.95	0.95	0.98	0.97	0.93	0.83	0.87	0.94	0.92	0.93	0.90	0.90	0.90	0.96	0.90	0.88	0.86	0.90
Chillán	0.99	0.98	0.99	0.95	0.88	0.78	0.83	0.86	0.95	0.95	0.97	0.96	0.92	1.00	1.00	0.99	0.99	0.98	0.94	0.94	0.97	0.98	0.99	1.00	1.00	0.98
Concepción	0.98	0.99	0.99	0.95	0.87	0.78	0.79	0.83	0.92	0.94	0.98	0.98	0.92	0.40	0.56	0.81	0.92	0.82	0.73	0.74	0.73	0.88	0.73	0.53	0.55	0.70
Los Ángeles	0.99	0.98	0.98	0.97	0.91	0.80	0.90	0.87	0.95	0.96	0.98	0.97	0.94	0.64	0.79	0.84	0.94	0.96	0.87	0.88	0.88	0.87	0.81	0.69	0.74	0.82
Angol	0.98	0.97	0.98	0.95	0.89	0.78	0.87	0.85	0.93	0.95	0.96	0.96	0.92	0.65	0.82	0.88	0.95	0.95	0.89	0.89	0.88	0.90	0.85	0.75	0.77	0.85
Curacautín	0.98	0.96	0.97	0.94	0.90	0.78	0.85	0.85	0.93	0.94	0.96	0.95	0.92	0.95	0.98	0.96	0.98	1.00	0.97	0.97	0.98	0.96	0.97	0.97	0.97	0.96
Temuco	0.97	0.94	0.96	0.91	0.89	0.76	0.81	0.83	0.91	0.92	0.94	0.94	0.90	0.98	1.00	1.00	1.00	1.00	1.00	0.98	0.97	0.99	1.00	1.00	1.00	0.99
Villarrica	0.97	0.95	0.95	0.92	0.87	0.74	0.81	0.81	0.90	0.92	0.94	0.93	0.89	1.00	1.00	0.99	0.99	1.00	0.97	0.97	0.97	0.97	0.99	1.00	0.99	0.98
Vadivia	0.96	0.96	0.94	0.91	0.80	0.64	0.76	0.74	0.86	0.90	0.89	0.91	0.85	0.95	0.93	0.96	0.96	0.96	0.91	0.94	0.91	0.93	0.92	0.91	0.87	0.93
Panguipulli	0.96	0.95	0.95	0.91	0.85	0.72	0.80	0.80	0.90	0.91	0.93	0.93	0.88	1.00	1.00	0.98	0.98	1.00	0.96	0.97	0.96	0.97	0.98	0.99	0.98	0.97
Osorno	0.95	0.94	0.94	0.89	0.86	0.80	0.83	0.80	0.92	0.91	0.92	0.93	0.89	0.95	0.97	0.98	0.98	1.00	0.99	0.98	0.98	0.98	0.96	0.97	0.98	0.98
Puerto Montt	0.92	0.93	0.87	0.86	0.80	0.70	0.79	0.75	0.88	0.90	0.90	0.88	0.85	0.95	0.95	0.98	0.93	0.82	0.64	0.79	0.70	0.90	0.91	0.93	0.93	0.87
Castro	0.88	0.89	0.86	0.87	0.77	0.72	0.78	0.75	0.86	0.88	0.88	0.88	0.83	0.88	0.88	0.94	0.92	0.88	0.75	0.85	0.79	0.89	0.89	0.88	0.92	0.88
Chaitén	0.89	0.89	0.86	0.89	0.78	0.74	0.79	0.77	0.87	0.88	0.92	0.89	0.85	0.95	0.95	0.97	0.91	0.93	0.85	0.93	0.89	0.95	0.95	0.95	0.96	0.94
Futaleufú	0.90	0.89	0.87	0.93	0.81	0.75	0.79	0.81	0.90	0.89	0.97	0.90	0.87	1.00	1.00	1.00	1.00	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Puerto Aysén	0.79	0.82	0.81	0.82	0.71	0.80	0.79	0.74	0.78	0.84	0.78	0.89	0.80	0.84	0.79	0.89	0.87	0.96	0.94	0.96	0.94	0.86	0.88	0.87	0.97	0.90
Coyhaique	0.93	0.98	0.94	0.86	0.88	0.80	0.89	0.91	0.94	0.89	0.93	0.93	0.91	0.97	0.99	1.00	1.00	0.99	1.00	1.00	1.00	0.98	1.00	1.00	0.97	0.99
Cochrane	0.89	0.93	0.90	0.86	0.84	0.84	0.88	0.87	0.90	0.89	0.89	0.93	0.88	0.74	0.76	0.80	0.79	0.83	0.84	0.83	0.83	0.82	0.78	0.77	0.79	0.80
Tortél	0.87	0.91	0.89	0.86	0.83	0.84	0.87	0.84	0.88	0.89	0.87	0.92	0.87	0.63	0.66	0.72	0.71	0.76	0.76	0.75	0.74	0.73	0.68	0.67	0.71	0.72
Puerto Natales	0.94	0.97	0.94	0.92	0.94	0.94	0.94	0.94	0.95	0.96	0.96	0.97	0.95	0.28	0.37	0.40	0.40	0.45	0.46	0.40	0.44	0.48	0.32	0.31	0.30	0.39
Punta Arenas	0.97	1.00	0.97	0.96	0.98	0.98	0.97	0.98	0.99	0.99	1.00	0.99	0.98	0.13	0.24	0.26	0.26	0.31	0.34	0.26	0.29	0.37	0.16	0.15	0.13	0.24
Puerto Williams	0.99	0.96	0.96	0.99	1.00	1.00	0.98	1.00	0.99	1.00	0.97	0.97	0.98	0.92	0.93	0.91	0.94	0.92	0.91	0.93	0.93	0.89	0.92	0.93	0.92	0.56

Figure 2.
Excerpt of monthly and annual climatic reduction coefficients

(continued)

Location (Chile)	Concrete (C)													Pavements (P)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Putre	1.00	1.00	1.00	1.00	0.98	0.96	0.95	0.96	0.97	0.97	0.99	1.00	0.98	1.00	1.00	1.00	0.99	0.97	0.96	0.95	0.94	0.97	0.98	0.99	1.00	0.98
Arica	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00
Iquique	1.00	1.00	1.00	1.00	0.99	0.97	0.99	0.99	0.98	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	0.99	0.97	0.99	0.99	0.98	0.99	0.99	0.99	0.99
Calama	1.00	1.00	1.00	0.97	0.74	0.62	0.51	0.55	0.71	0.76	0.95	1.00	0.82	1.00	0.99	1.00	0.96	0.73	0.62	0.50	0.55	0.70	0.76	0.95	1.00	0.81
Antofagasta	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00
Atacama dessert	1.00	1.00	1.00	1.00	0.99	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.97	1.00	0.97	0.99	1.00	1.00	1.00	1.00	0.99
Copiapo	1.00	1.00	1.00	1.00	0.99	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	0.98	0.99	0.97	0.98	1.00	1.00	1.00	1.00	0.99
Vallenar	1.00	1.00	1.00	1.00	0.99	0.99	0.97	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.97	0.97	0.96	0.97	1.00	0.99	1.00	1.00	0.99
La Serena	1.00	1.00	1.00	1.00	0.99	0.97	0.97	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	0.96	0.95	0.94	0.95	0.99	0.98	1.00	1.00	0.98
Vicuña	1.00	1.00	1.00	1.00	0.98	0.96	0.95	0.96	0.99	0.99	0.99	1.00	0.99	1.00	1.00	1.00	0.99	0.95	0.93	0.92	0.93	0.97	0.98	0.99	1.00	0.97
Ovalle	1.00	1.00	1.00	1.00	0.98	0.95	0.96	0.97	0.99	0.99	0.99	1.00	0.99	1.00	1.00	1.00	0.99	0.96	0.91	0.93	0.93	0.97	0.98	0.99	1.00	0.97
Illapel	1.00	1.00	1.00	1.00	0.98	0.92	0.94	0.94	0.99	0.99	0.99	1.00	0.98	1.00	1.00	1.00	0.98	0.94	0.87	0.90	0.89	0.96	0.97	0.98	0.99	0.96
Los Andes	1.00	1.00	1.00	0.99	0.94	0.84	0.82	0.86	0.98	0.98	0.99	0.99	0.96	0.99	0.99	0.99	0.97	0.91	0.77	0.79	0.82	0.93	0.96	0.97	0.98	0.92
Valparaíso	1.00	1.00	1.00	0.99	0.97	0.89	0.95	0.92	0.98	0.98	0.99	0.99	0.97	1.00	0.99	0.99	0.98	0.92	0.80	0.88	0.86	0.96	0.96	0.98	0.98	0.94
Rodelillo	1.00	1.00	1.00	0.99	0.98	0.89	0.97	0.93	0.99	0.98	0.99	0.99	0.98	1.00	1.00	1.00	0.99	0.94	0.81	0.91	0.88	0.97	0.96	0.98	0.98	0.95
Santo Domingo	1.00	1.00	1.00	0.99	0.95	0.87	0.88	0.90	0.97	0.99	1.00	1.00	0.96	1.00	0.99	0.99	0.97	0.89	0.77	0.79	0.79	0.92	0.95	0.98	0.99	0.92
Pudahuel	1.00	1.00	1.00	0.99	0.87	0.76	0.66	0.78	0.97	0.99	0.99	1.00	0.92	0.99	0.99	0.98	0.96	0.81	0.68	0.60	0.71	0.91	0.97	0.97	1.00	0.88
Quinta Normal	1.00	1.00	0.99	0.99	0.94	0.84	0.82	0.88	0.98	0.99	0.99	1.00	0.95	0.99	0.99	0.98	0.96	0.89	0.75	0.74	0.80	0.92	0.95	0.97	1.00	0.91
Tobalaba	1.00	1.00	1.00	0.99	0.97	0.85	0.81	0.85	0.98	0.99	0.98	1.00	0.95	0.99	0.99	0.99	0.96	0.93	0.77	0.76	0.78	0.91	0.95	0.96	1.00	0.92
Rancagua	1.00	0.99	0.99	0.98	0.90	0.80	0.76	0.81	0.96	0.98	0.99	0.99	0.93	0.98	0.98	0.98	0.95	0.85	0.71	0.68	0.72	0.90	0.93	0.96	0.98	0.89
Pichilemu	0.99	0.99	0.99	0.98	0.90	0.82	0.78	0.84	0.96	0.98	0.99	0.99	0.94	0.99	0.98	0.98	0.95	0.82	0.70	0.70	0.72	0.91	0.92	0.96	0.97	0.88
Curicó	0.99	1.00	0.99	0.96	0.84	0.75	0.70	0.76	0.95	0.97	0.99	1.00	0.91	0.98	0.99	0.98	0.93	0.78	0.64	0.60	0.65	0.91	0.91	0.96	0.96	0.86
Talca	0.99	0.99	0.99	0.95	0.84	0.74	0.71	0.75	0.94	0.96	0.98	0.99	0.90	0.98	0.98	0.96	0.91	0.76	0.60	0.59	0.62	0.87	0.88	0.94	0.95	0.84
Linares	0.99	0.99	0.99	0.95	0.82	0.72	0.68	0.74	0.92	0.96	0.98	0.98	0.89	0.97	0.96	0.95	0.90	0.74	0.57	0.56	0.60	0.84	0.87	0.93	0.94	0.82
Cauquenes	0.99	0.99	0.99	0.95	0.84	0.74	0.72	0.75	0.92	0.95	0.98	0.97	0.90	0.96	0.96	0.94	0.89	0.74	0.56	0.57	0.60	0.84	0.85	0.91	0.93	0.81
Chillán	0.99	0.98	0.99	0.93	0.80	0.69	0.66	0.70	0.90	0.95	0.97	0.96	0.88	0.95	0.94	0.93	0.87	0.71	0.53	0.53	0.54	0.80	0.84	0.90	0.92	0.79
Concepción	0.98	0.99	0.99	0.94	0.86	0.75	0.75	0.77	0.90	0.94	0.98	0.98	0.90	0.95	0.94	0.91	0.86	0.73	0.51	0.55	0.57	0.80	0.80	0.85	0.90	0.78
Los Ángeles	0.99	0.98	0.98	0.95	0.86	0.73	0.73	0.76	0.85	0.95	0.97	0.97	0.89	0.96	0.94	0.94	0.90	0.77	0.55	0.61	0.64	0.78	0.86	0.91	0.92	0.82
Angol	0.98	0.98	0.97	0.91	0.82	0.70	0.69	0.72	0.82	0.92	0.96	0.96	0.87	0.94	0.92	0.90	0.82	0.70	0.49	0.52	0.55	0.72	0.78	0.84	0.87	0.76
Curacautín	0.98	0.96	0.96	0.88	0.76	0.66	0.61	0.64	0.79	0.90	0.94	0.95	0.84	0.91	0.90	0.86	0.79	0.64	0.44	0.44	0.48	0.64	0.73	0.82	0.83	0.71
Temuco	0.97	0.94	0.95	0.84	0.74	0.65	0.59	0.62	0.76	0.87	0.91	0.94	0.82	0.88	0.88	0.81	0.69	0.57	0.39	0.37	0.40	0.58	0.64	0.74	0.77	0.65
Villarrica	0.97	0.95	0.95	0.86	0.73	0.62	0.59	0.61	0.76	0.88	0.92	0.93	0.81	0.87	0.87	0.81	0.70	0.56	0.38	0.39	0.41	0.60	0.65	0.76	0.77	0.65
Vadivia	0.96	0.96	0.94	0.89	0.72	0.57	0.62	0.61	0.75	0.88	0.89	0.91	0.81	0.84	0.84	0.77	0.68	0.52	0.35	0.43	0.41	0.58	0.62	0.71	0.71	0.62
Panguipulli	0.96	0.95	0.94	0.86	0.72	0.62	0.59	0.59	0.76	0.87	0.91	0.93	0.81	0.86	0.85	0.79	0.69	0.55	0.38	0.38	0.39	0.59	0.64	0.74	0.75	0.64
Osorno	0.95	0.94	0.93	0.85	0.71	0.66	0.63	0.62	0.79	0.88	0.91	0.93	0.82	0.82	0.81	0.75	0.68	0.53	0.40	0.39	0.36	0.54	0.62	0.71	0.73	0.61
Puerto Montt	0.92	0.93	0.87	0.85	0.68	0.58	0.61	0.58	0.74	0.86	0.90	0.88	0.78	0.70	0.71	0.60	0.54	0.44	0.28	0.31	0.31	0.43	0.47	0.65	0.56	0.50
Castro	0.88	0.89	0.86	0.83	0.69	0.58	0.60	0.56	0.74	0.83	0.87	0.88	0.77	0.69	0.68	0.62	0.57	0.45	0.37	0.37	0.37	0.50	0.53	0.67	0.64	0.53
Chaitén	0.89	0.89	0.86	0.80	0.67	0.54	0.51	0.50	0.72	0.80	0.91	0.89	0.75	0.72	0.71	0.68	0.59	0.46	0.35	0.34	0.36	0.52	0.57	0.75	0.73	0.57
Futaleufú	0.90	0.89	0.87	0.76	0.65	0.49	0.41	0.42	0.69	0.77	0.97	0.90	0.73	0.79	0.77	0.79	0.65	0.48	0.34	0.32	0.37	0.61	0.65	0.87	0.85	0.62
Puerto Aysén	0.79	0.82	0.81	0.82	0.71	0.63	0.68	0.62	0.77	0.80	0.73	0.87	0.75	0.70	0.71	0.60	0.54	0.44	0.28	0.31	0.31	0.43	0.47	0.65	0.56	0.50
Coyhaique	0.93	0.98	0.92	0.74	0.59	0.47	0.52	0.52	0.78	0.81	0.92	0.92	0.76	0.72	0.79	0.68	0.56	0.40	0.29	0.35	0.39	0.56	0.63	0.73	0.73	0.57
Cochrane	0.89	0.93	0.89	0.79	0.66	0.54	0.58	0.57	0.78	0.82	0.86	0.92	0.77	0.66	0.70	0.62	0.55	0.44	0.40	0.41	0.44	0.52	0.61	0.67	0.73	0.56
Tortél	0.88	0.91	0.87	0.81	0.68	0.56	0.60	0.59	0.78	0.82	0.83	0.91	0.77	0.64	0.66	0.60	0.53	0.45	0.44	0.44	0.45	0.52	0.60	0.64	0.72	0.56
Puerto Natales	0.94	0.95	0.92	0.84	0.72	0.54	0.52	0.58	0.78	0.84	0.92	0.96	0.79	0.69	0.70	0.67	0.56	0.53	0.41	0.39	0.45	0.58	0.64	0.71	0.75	0.59
Punta Arenas	0.97	0.98	0.95	0.85	0.73	0.51	0.49	0.57	0.78	0.84	0.95	0.98	0.80	0.71	0.72	0.70	0.57	0.57	0.39	0.38	0.45	0.61	0.66	0.74	0.78	0.61
Puerto Williams	1.00	0.99	0.98	0.98	0.95	0.89	0.91	0.92	0.96	0.97	0.99	0.99	0.78	0.76	0.71	0.77	0.69	0.58	0.33	0.33	0.45	0.73	0.74	0.73	0.70	0.63

Figure 2.

Table II. Performance comparisons homogeneizing the climatic influence in six bridges built by the same contractor

				Location: Puerto Montt														
				Bridge A (14 m) starting date: February 15, 2011					Bridge B (20 m) starting date: December 19, 2011					Bridge C (22 m) starting date: June 27, 2012				
WBS	Units	Activity (description)	Climatic coeff. (identification)	Quantity (Q) (units)	Actual duration (AD) (working days)	Raw perform. (RP = Q/AD) (units/day)	Climatic coeff. (C) (avg. monthly values)	Actual perform. (AP = RP/C) (units/day)	Quantity (Q) (units)	Actual duration (AD) (working days)	Raw perform. (RP = Q/AD) (units/day)	Climatic coeff. (C) (avg. monthly values)	Actual perform. (AP = RP/C) (units/day)	Quantity (Q) (units)	Actual duration (AD) (working days)	Raw perform. (RP = Q/AD) (units/day)	Climatic coeff. (C) (avg. monthly values)	Actual perform. (AP = RP/C) (units/day)
1.1	m^3	General … bridge excavations	Earthworks	1,637	11	148.8	0.93	160.0	2,137	13	168.1	1.00	168.1	2,292	21	108.3	0.72	150.4
1.2	m^3	Structural fillings	Earthworks	1,710	22	77.7	0.77	100.9	1,779	20	91.0	0.97	93.8	1,967	24	82.0	0.98	83.7
1.3	m^3	Lean concrete (5 MPa)	Concrete	25	1	25.0	0.81	30.9	26	1	26.9	0.90	29.8	29	2	16.2	0.49	33.1
1.4	m^3	Structural concrete (30 MPa)	Concrete	594	8	74.3	0.76	97.7	832	8	98.9	0.92	107.5	838	10	84.8	0.86	98.6
1.5	kg	Reinforcing steel (A63-42H)	None	71,280	24	2,970.0	1.00	2,970.0	101,218	30	3,333.9	1.00	3,333.9	99,507	35	2,862.5	1.00	2,862.5
1.6	m^2	Formworks	Formworks	1,299	26	50.0	1.00	50.0	1,897	35	54.6	0.96	57.1	1,845	55	33.7	0.77	43.7
1.7	ud	Drainage system	None	1	2	0.5	1.00	0.5	1	2	0.5	1.00	0.5	1	2	0.5	1.00	0.5
1.8	m	Concrete … wall sections install.	None	28	3	9.3	1.00	9.3	40	5	8.0	1.00	8.0	44	5	8.1	1.00	8.1
2.1	m^3	Scarp excavations	Earthworks	150	1	150.0	0.81	186.0	157	1	180.8	0.90	200.2	207	1	174.7	0.81	215.7
2.2	m^3	Embankment excavation	Earthworks	438	3	146.0	0.81	181.0	622	4	162.8	0.90	180.8	636	4	158.6	0.81	195.8
2.3	m^2	Embankment … and compacting	Earthworks	1,824	10	182.4	0.77	236.9	2,592	10	263.5	0.97	272.3	2,518	11	234.1	0.97	241.4
2.4	m^2	Subgrade preparation	Earthworks	1,520	7	217.1	0.77	280.5	2,220	10	232.9	0.95	245.1	2,098	7	311.4	0.98	317.8
2.5	m^3	Granular base (CBR≥80%)	Earthworks	369	3	123.0	0.77	158.9	532	3	167.1	0.93	179.7	572	3	172.4	1.00	172.4
2.6	m^2	Asphalt sheet primer	Pavements	1,538	2	769.0	0.32	2,419.9	2,169	2	1,147.7	0.53	2,152.0	2,231	1	2,061.2	0.80	2,576.5
2.7	m^2	Tack coats	Pavements	1,200	2	600.0	0.27	2,222.2	1,704	3	647.8	0.32	2,024.5	1,764	3	660.3	0.35	1,886.7

(continued)

2.8	m^3	Asphalt surface road	Pavements	106	3	35.3	0.27	130.9	150	3	44.7	0.32	139.7	155	1	114.4	0.80	142.9
2.9	m^3	Coarse-grained hot asphalt mix	Pavements	108	3	36.0	0.27	133.3	154	2	63.0	0.53	118.1	153	1	103.4	0.80	129.2
				Location: Osorno														
				Bridge A (15 m) starting date: February 15, 2011					Bridge B (24 m) starting date: December 1, 2011					Bridge C (24,5 m) starting date: May 1, 2012				
1.1	m^3	General … bridge excavations	Earthworks	1,679	12	137.2	0.90	152.5	2,771	20	141.7	0.94	150.8	2,827	24	118.2	0.74	159.7
1.2	m^3	Structural fillings	Earthworks	1,878	22	84.8	0.98	86.5	3,005	35	85.3	0.93	91.7	2,855	36	78.7	0.83	94.8
1.3	m^3	Lean concrete (5 MPa)	Concrete	26	1	24.5	0.81	30.2	42	1	29.8	1.00	29.8	43	3	16.2	0.57	28.4
1.4	m^3	Structural concrete (30 MPa)	Concrete	599	9	69.8	0.82	85.1	911	12	74.9	0.86	87.1	939	18	52.8	0.59	89.5
1.5	kg	Reinforcing steel (A63-42H)	None	72,717	31	2,379.2	1.00	2,379.2	115,621	50	2,330.1	1.00	2,330.1	119,321	53	2,249.6	1.00	2,249.6
1.6	m^2	Formworks	Formworks	1,336	27	48.7	1.00	48.7	2,071	43	48.6	1.00	48.6	2,144	42	51.7	1.00	51.7
1.7	ud	Drainage system	None	1	2	0.5	1.00	0.5	1	2	0.5	1.00	0.5	1	2	0.5	1.00	0.5
1.8	m	Concrete … wall sections install	None	30	3	9.2	1.00	9.2	48	6	8.1	1.00	8.1	49	6	8.1	1.00	8.1
2.1	m^3	Scarp excavations	Earthworks	152	1	148.9	0.84	177.3	224	1	182.3	1.00	182.3	189	2	125.3	0.74	169.3
2.2	m^3	Embankment excavation	Earthworks	496	4	125.8	0.84	149.8	793	5	156.9	1.00	156.9	754	6	119.9	0.74	162.1
2.3	m^2	Embankment … and compacting	Earthworks	2,056	14	147.4	0.74	199.2	3,249	17	196.8	0.93	211.6	3,217	23	139.2	0.77	180.8
2.4	m^2	Subgrade preparation	Earthworks	1,713	8	210.1	0.87	241.5	2,673	10	254.7	1.00	254.7	2,700	15	176.3	0.77	228.9
2.5	m^3	Granular base (CBR≥80%)	Earthworks	388	3	132.0	0.87	151.7	608	4	157.0	1.00	157.0	633	5	135.3	0.87	155.5
2.6	m^2	Asphalt sheet primer	Pavements	1,570	2	676.4	0.31	2,182.0	2,434	2	1,516.3	0.77	1,969.2	2,442	2	1,294.7	0.57	2,271.4
2.7	m^2	Tack coats	Pavements	1,251	2	690.3	0.37	1,865.6	1,952	1	1,457.1	0.77	1,892.3	2,011	2	1,301.8	0.72	1,808.1
2.8	m^3	Asphalt surface road	Pavements	108	3	41.1	0.37	111.0	167	2	93.7	0.77	121.7	175	2	80.2	0.72	111.4
2.9	m^3	Coarse-grained hot asphalt mix	Pavements	112	2	44.9	0.34	132.0	175	2	93.5	0.77	121.4	181	3	68.1	0.57	119.4

(continued)

Table II.

Table II.

				Raw performances comparison Resid. = │RPother bridge/RPPuerto Montt bridge A−1│						Residuals comparison				Actual performances comparison Resid. = │APother bridge/APPuerto Montt bridge A−1│				
				Puerto Montt Bridge B	Puerto Montt Bridge C	Osorno Bridge A	Osorno Bridge B	Osorno Bridge C	Σ (by rows)	Σ (residuals)	Clim. Coeff.		Σ (by rows)	Puerto Montt Bridge B	Puerto Montt Bridge C	Osorno Bridge A	Osorno Bridge B	Osorno Bridge C
1.1	m^3	General … bridge excavations	Earthworks	0.13	0.27	0.08	0.05	0.21	0.73	5.85	Earthworks		0.22	0.05	0.06	0.05	0.06	0.00
1.2	m^3	Structural fillings	Earthworks	0.17	0.06	0.09	0.10	0.01	0.43	0.51	Formworks		0.54	0.07	0.17	0.14	0.09	0.06
1.3	m^3	Lean concrete (5 MPa)	Concrete	0.08	0.35	0.02	0.19	0.35	0.99	1.83	Concrete		0.24	0.03	0.07	0.02	0.04	0.08
1.4	m^3	Structural concrete (30 MPa)	Concrete	0.33	0.14	0.06	0.01	0.29	0.83	17.82	Pavements		0.43	0.10	0.01	0.13	0.11	0.08
1.5	kg	Reinforcing steel (A63-42H)	None	0.12	0.04	0.20	0.22	0.24	0.82	1.65	None		0.82	0.12	0.04	0.20	0.22	0.24
1.6	m^2	Formworks	Formworks	0.09	0.33	0.02	0.03	0.03	0.51		↘	% of reduction	0.35	0.14	0.12	0.02	0.03	0.03
1.7	ud	Drainage system	None	0.01	0.10	0.09	0.01	0.07	0.28			43.98	0.28	0.01	0.10	0.09	0.01	0.07
1.8	m	Concrete … wall sections install	None	0.14	0.13	0.02	0.13	0.14	0.56			30.05	0.56	0.14	0.13	0.02	0.13	0.14
												63.04						
2.1	m^3	Scarp excavations	Earthworks	0.21	0.16	0.01	0.22	0.16	0.76			88.01	0.39	0.08	0.16	0.05	0.02	0.09
2.2	m^3	Embankment excavation	Earthworks	0.11	0.09	0.14	0.07	0.18	0.59		↗	0.00	0.49	0.00	0.08	0.17	0.13	0.10
2.3	m^2	Embankment … and compacting	Earthworks	0.44	0.28	0.19	0.08	0.24	1.24		Clim. Coeff.	Σ (residuals)	0.67	0.15	0.02	0.16	0.11	0.24
2.4	m^2	Subgrade preparation	Earthworks	0.07	0.43	0.03	0.17	0.19	0.90				0.67	0.13	0.13	0.14	0.09	0.18
2.5	m^3	Granular base (CBR⩾80%)	Earthworks	0.36	0.40	0.07	0.28	0.10	1.21		Earthworks	3.28	0.29	0.13	0.09	0.05	0.01	0.02
2.6	m^2	Asphalt sheet primer	Pavements	0.49	1.68	0.12	0.97	0.68	3.95		Formworks	0.35	0.52	0.11	0.06	0.10	0.19	0.06
2.7	m^2	Tack coats	Pavements	0.08	0.10	0.15	1.43	1.17	2.93		Concrete	0.67	0.74	0.09	0.15	0.16	0.15	0.19
2.8	m^3	Asphalt surface road	Pavements	0.27	2.24	0.16	1.65	1.27	5.59		Pavements	2.14	0.53	0.07	0.09	0.15	0.07	0.15
2.9	m^3	Coarse-grained hot asphalt mix	Pavements	0.75	1.87	0.25	1.60	0.89	5.35		None	1.65	0.35	0.11	0.03	0.01	0.09	0.10

and the columns for each bridge indicate the type of climatic reduction coefficients applied, the quantities (Q), the actual activity duration (AD), the raw activity performance (RP) in which the weather effect was not yet considered, the average climatic reduction coefficient (C) calculated as the weighted average value of the month in which the activity was performed and the actual activity performance (AP) calculated as the RP divided by C, as mentioned above. Therefore, since AP values represent the productivity rate actually reached for construction activities during the days in which their respective weather-related events did not happen, AP values are consistently higher or equal to RP values.

Obviously, several activities were removed from the bridge construction to compare all of them under very similar conditions. In addition, all of the activities mainly included concrete; thus, the steelworks coefficients were not represented in previous tables and figures.

As observed above, the important aspects to be compared include how the activity performance is similar and when the climatic reduction coefficients are considered. In this case, the table at the bottom summarizes and compares the raw performances (RP) on the left and the actual performances (AP) on the right by initially dividing each activity (raw (left) or actual (right) performances) for all bridges (except Puerto Montt Bridge A) based on the raw or actual performances, respectively, of Puerto Montt Bridge A. These preliminary performance ratios are obtained to homogenize the sizes of the performance deviations to avoid comparing performance values with orders of magnitude that are very different. Next, the residuals are easily obtained by subtracting them from one and by calculating the absolute values of these differences.

The results are easy to read and are numerically expressed at the bottom of Table II, where the sub-table "% of reduction" provides evidence based on the climatic reduction coefficient or the fraction that the actual performance residuals have decreased relative to the raw performance residuals. Therefore, when activity performances are compared by accounting for the climatic variables expressed above, the values are significantly similar.

Of course, this case study does not prove that all outdoor construction work must follow the same pattern regarding climate. However, it notes that the method shown here likely accounts for the first step in the right direction to forecast construction project delays.

Validation

Choosing validation methods in construction productivity research is challenging (Liu *et al.*, 2014) because project productivity generally depends on work methodologies, a lack of supervision and material supply (among other issues and as previously indicated regarding the main factors influencing project delays). However, other variables exist, such as the climatic variables described above. Nevertheless, by comparing six similar bridge constructions in a relatively nearby location that were built by the same experienced contractors during a short time, we can safely assume that differences concerning work methodologies, supervision and material supplies cannot be very relevant among the analyzed works to have caused important bias in the results.

Of course, the developed case study cannot be considered universal because the available data result from one country and the example uses a single type of civil work (bridges in this case). Nevertheless, it is worth highlighting that this study is methodologically representative because it shows how a handful of climatic variables greatly affect the performance of outdoor activities. In this case, different countries suffer from different weather conditions and are generally addressed using different work methodologies. Therefore, although the specific weather variables chosen for other locations could differ, this case study provides a selection of tools that can be used for these climatic conditions to turn them into climatic reduction coefficients for estimating project activity delays.

It is still important to determine whether the statistical expressions linking project productivity with the set of climatic reduction coefficients are reliable beyond the residual analysis when considering the available bridge performance data.

Regarding these expressions, some simplifications are assumed because the problem analyzed includes a complex, multiple non-linear regression analysis for each set of activities that share the same climatic reduction coefficient.

Thus, we can state this problem as follows: the forecast of the actual activity performances (AP) of the five bridges (dependent Y variables) is a function of the actual activity performances of the Puerto Montt Bridge A (independent X variables).

For example, the earthworks actual activity performances regression expressions could be written for the same activity as follows:

$$AP_{other\ \ bridge} = \frac{RP_{other\ \ bridge}}{C_{p10\ \ other\ \ bridge}} = \frac{RP_{Puerto\ \ Monttr\ \ bridge\ \ A}}{C_{p10\ \ Puerto\ \ Monttr\ \ bridge\ \ A}} = AP_{Puerto\ \ Monttr\ \ bridge\ \ A} \tag{10}$$

By solving this expression, the following equation is obtained:

$$RP_{other\ \ bridge} = \frac{C_{p10\ \ other\ \ bridge}}{C_{p10\ \ Puerto\ \ Monttr\ \ bridge\ \ A}} \cdot RP_{Puerto\ \ Monttr\ \ bridge\ \ A} \tag{11}$$

This expression would allow us to calculate the actual activity duration (AD) once the quantity (Q) of work is known (AD = Q/RP), a duration which already accounts for non-working days.

Equation (11) has three variables that cannot be isolated linearly to independently measure their individual contributions and significance. Furthermore, the raw activity performances of concrete and pavement depend on five variables rather than three variables because they implement two different raw climatic coefficients (which are also applied twice each in Equation (11)).

However, a viable and easier alternative exists for obtaining this multi-variable complex regression analysis that consists of linearizing the expressions by considering the left side of Equation (11) as a single independent variable (X) for forecasting the RPs of the five bridges (that is Y, just as $Y = a + b \cdot X$).

In this sense, if Equation (11) actually represents an accurate expression, the following should be observed:

- Intercept (a) values near zero and coefficients of determination (R^2) near one.
- Slopes (b) near one indicating that the linearized variables depict the Y variability without the need of other numerical coefficients, such as intercepts.
- p-Values near zero that confirm that the regression results were not caused randomly and that the slopes are representative. Regarding the p-values, either the student t-test or Fisher F-test can be used. However, we used the Fisher F-test.

In synthesis, eight simple linear regression analyses were performed (four without a constraint for the intercept and four with the intercepts set to zero) to determine the raw activity performances under the same four climatic reduction coefficients. The most important results are shown in Table III.

In nearly every case, the above stated conditions were fulfilled, but only for the Formwork activities when the intercept was not set to zero. This result actually occurred because the bridge set of activities only contained a single formwork-related activity. Thus, these raw performance values were always located on the same vertical line, which eliminated the need for calculating a regression line with a free intercept.

In contrast, the intercept values could be considered relatively small (earthworks intercept included), especially when compared with the order of magnitude of their respective actual activity performance values.

In addition to the first residual analysis, we linearized the regression variables to allow for an approximate analysis. The drawbacks include that the possible correlations among variables cannot be calculated and that the analysis developed is only valid for bridges that are introduced in the case study. However, despite these drawbacks, this method is considered acceptable for a first approximation because other work methodologies or country weather conditions could cause variations in the raw performances forecasting method. Thus, the approach presented above is methodological rather than numerically exact or universal. Therefore, the authors acknowledge that a better climatic variable configuration must exist in other outdoor construction activities or locations.

Case study generalization

Hence, now that a case involving an actual linear construction project has been explained and validated, a more general case study is analyzed to illustrate how climatic reduction coefficients have two other major purposes (other than homogenizing the comparison of activity performances).

This two-fold purpose is to prove that the very same construction project may require very different time intervals for building depending on where and when it is built. To prove these logical statements, we considered a 14-meter bridge that was built in Puerto Montt (the first Bridge A). In addition, to simplify the calculations, the performance ratios were estimated before construction (and consequently differ from the actual values shown in Table II for Puerto Montt Bridge A) to simulate what would occur during the planning phase of any construction project.

Accounting for these methods, Table IV quantitatively defines the construction works that are necessary for building a simplified 14-meter concrete bridge without considering climatic influences. Figure 3 depicts the Gantt chart for the same bridge

Table III. Actual performance regression analysis results for the six bridges

Climatic coefficient	Least squares regression line $Y = a+b \cdot X$				Least squares regression line (intercept = 0) $Y = b \cdot X$			
	Intercept (a)	Slope (b)	R^2	p-value	Intercept (a)	Slope (b)	R^2	p-value
Earthworks	10.115	0.901	0.838	1.34E−14	0.000	0.951	0.823	1.85E−33
Formworks	−inf	+inf	1	0	0.000	1.000	0.741	2.19E−05
Concrete	1.021	0.947	0.965	6.99E−09	0.000	0.959	0.957	7.00E−11
Pavements	3.692	0.889	0.985	6.91E−18	0.000	0.890	0.984	3.86E−22

Table IV.
Standard 14-meter bridge works

WBS	Units	Activity (description)	Quantity (Q) (units)	Performance (P) (units/day)	Duration (Q/P) (rough days)	Duration (rounded-off working days)	Predecessors (activities' ID*)	Climatic coeff. (identification)
1. Structure								
1.1	m^3	General and structural bridge excavations	1,637	160	10.23	11	Start	Earthworks
1.2	m^3	Structural fillings	1,710	80	21.38	22	1.4	Earthworks
1.3	m^3	Lean concrete (5 MPa)	25	100	0.25	1	1.1	Concrete
1.4	m^3	Structural concrete (30 MPa)	594	80	7.43	8	1.6	Concrete
1.5	kg	Reinforcing steel (A63-42H)	71,280	3,000	23.76	24	1.3	None
1.6	m^2	Formworks	1,299	50	25.98	26	[50%] 1.5	Formworks
1.7	ud	Drainage system	1	0.5	2.00	2	1.2	None
1.8	m	Concrete protection wall sections installation	28	10	2.80	3	1.7	None**
2. Accesses and complementary works								
2.1	m^3	Scarp excavations	150	160	0.94	1	1.1	Earthworks
2.2	m^3	Embankment excavation	438	160	2.74	3	2.1	Earthworks
2.3	m^2	Embankment formation and compacting	1,824	200	9.12	10	1.4; 2.2	Earthworks
2.4	m^2	Subgrade preparation	1,520	250	6.08	7	2.3	Earthworks
2.5	m^3	Granular base (CBR $\geqslant$ 80%)	369	150	2.46	3	2.4	Earthworks
2.6	m^2	Asphalt sheet primer	1,538	1,000	1.54	2	1.8; 2.5	Pavements
2.7	m^2	Tack coats	1,200	1,000	1.20	2	2.6	Pavements
2.8	m^3	Asphalt surface road	106	50	2.12	3	2.7	Pavements
2.9	m^3	Coarse-grained hot asphalt mix	108	50	2.16	3	2.8	Pavements

Notes: *All activities' precedence relationships are finish-start apart from activity 6 that has a Start-Start precedence with activity 5 with a delayed lag equivalent to 50 percent of the activity's 5 duration. Activity 5 has a delay equivalent to 50 percent of the duration of activities 5 and 1.5; **Because the concrete wall sections will be provided by a supplier and built at the construction site, this activity is not influenced by weather conditions

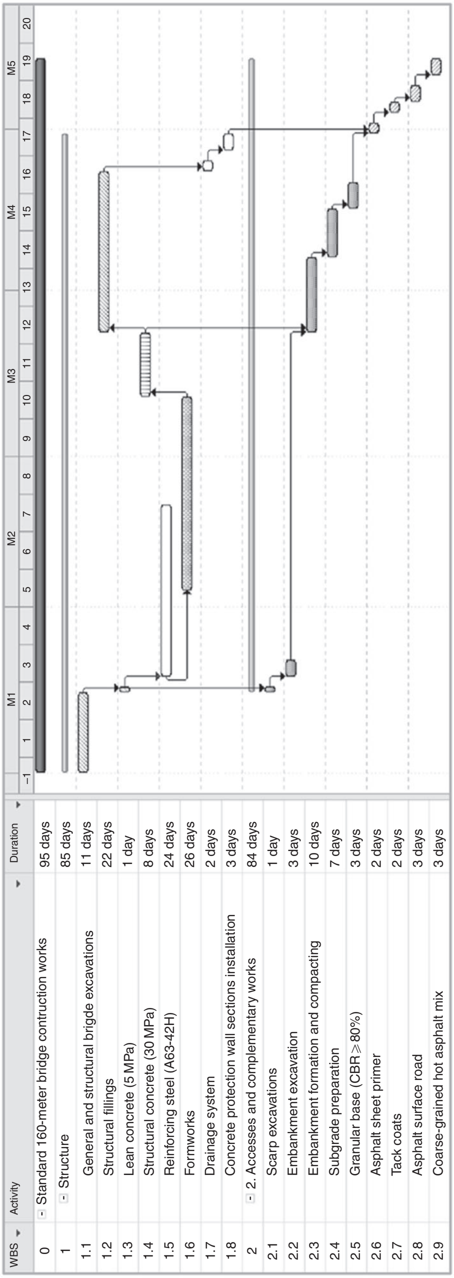


Figure 3.
Standard gantt chart for 14-meter bridge works

considering activity durations under the same conditions and the precedence relationships among them.

Now that a bridge construction project has been defined, the next logical step is to compare how long this very same bridge would have taken to be built at different locations in Chile and when starting at different times of the year. For this estimation, each construction activity listed in Table IV will be lengthened based on its duration divided by its respective climatic reduction coefficient (constant for the same location but different for each month of the year). The interesting results that were obtained are shown in Table V.

The four locations selected in Table V (Iquique, Rancagua, Puerto Montt and Puerto Natales) are spaced approximately equidistantly from North (dessert climate) to South (humid and much colder climate) and indicate four completely different climatic settings. In contrast, the four different starting dates illustrate how the same construction projects could require different amounts of time to finish compared to the standard bridge construction duration without climatic influence (top row in light gray).

The fictitious example summarized in Table V along with the real examples shown in Table II provide meaningful insights regarding the climatic influences of construction activity performances and durations relative to construction project delays.

Discussion

Project delays are relatively frequent in the construction industry and are associated with wasting natural, material and economic resources. The location and timing of construction projects affect project delays, and the exact location of a project cannot always be altered. However, the particular moment of time can frequently be modified.

Location (Chile)	Information displayed	Starting date: January 1	April 1	July 1	October 1	Difference between max. and min.
Standard project	Finish date without climatic influence	May 15	August 14	November 14	February 12	
	Duration without climatic influence (calendar days)	135	136	137	135	
Iquique	Finish date with climatic influence	August 1st	August 29	December 2	March 11	
	Duration with climatic influence (calendar days)	213	151	155	162	62
	Time extension (%)	158	111	113	120	47
Rancagua	Finish date with climatic influence	May 28	September 3	November 26	February 25	
	Duration with climatic influence (calendar days)	148	156	149	147	9
	Time extension (%)	110	115	109	109	6
Puerto Montt	Finish date with climatic influence	June 27	October 14	December 22	March 6	
	Duration with climatic influence (calendar days)	178	197	175	157	40
	Time extension (%)	132	145	128	116	29
Puerto Natales	Finish date with climatic influence	August 19	October 29	January 15	May 29	
	Duration with climatic influence (calendar days)	231	212	199	241	42
	Time extension (%)	171	156	145	179	33

Table V. Schedule alterations planned as a function of climatology in four regions of Chile

The method shown above presents a straightforward demonstration of how varying the project starting dates can result in noticeably different durations. Of course, the longer the construction work takes, the less the monthly climatic reduction coefficients will influence each activity, which will reduce the importance of the exact moment the project starts. However, even in these cases, the weather effects can produce deviations in project durations of approximately 10 percent.

In contrast, the actual case study has indicated how the activity performances are more similar when the climatic factor is considered, which is another useful outcome of this study because the method serves as a new tool when estimating more reliable, future construction activity performances during the planning phase and results in the creation of a method for estimating non-working days due to climate eventually useful for both contractors and public clients.

Conclusions

The influences of climate are frequently cited as a source of construction project delays. However, very few studies have thoroughly tackled analyzing the influences of major climatic agents on the most common outdoor construction activities.

As shown in this paper, despite the fact that it is nearly impossible to find an exact relationship between how each weather event or combinations of weather events influence each construction activity, construction managers should not hesitate to implement procedures that enable them to improve their current estimations of potentially activity-specific non-working days due to weather phenomena.

The method detailed here provide a fairly simple and quick approximation that is useful for project and risk managers and construction planners to address climatic agents to decide how much extra time will be needed to build an outdoor construction project, calculate when it would be more advisable to start the on-site work while minimize adverse weather conditions and time delays as much as possible, compare the activity performances under more homogeneous conditions, and serve as a planning guide and terms of agreement when the developer (public or private) and the contractor are determining how many days on average will be considered as non-productive days due to the climate.

In this analysis, all of these points were discussed based on six actual bridge construction projects built in Chile and on a more general case study that illustrated the influence of the starting date over the final project duration. However, the findings described here are not restricted to Chile because the devised method is equally applicable to any other country that keeps climate records (i.e. the vast majority of countries). Thus, it is expected that the effectiveness will remain the same when trying to avoid economic, social and environmental impacts that generally delay construction projects and frequently occur.

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