THE INFLUENCE OF PROJECT COMPLEXITY ON ESTIMATING ACCURACY

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With the rapid development in technology over recent years, construction, in common with many areas of industry, has become increasingly complex. It would, therefore, seem to be important to develop and extend the understanding of complexity so that industry in general and in this case the construction industry can work with greater accuracy and efficiency to provide clients with a better service. This paper aims to generate a definition of complexity and a method for its measurement in order to assess its influence upon the accuracy of the quantity surveying profession in UK new build office construction. Quantitative data came from an analysis of twenty projects of varying size and value and qualitative data came from interviews with professional quantity surveyors. The findings highlight the difficulty in defining and measuring project complexity. The correlation between accuracy and complexity was not straightforward, being subjected to many extraneous variables, particularly the impact of project size. Further research is required to develop a better measure of complexity. This is in order to improve the response of quantity surveyors, so that an appropriate level of effort can be applied to individual projects, permitting greater accuracy and enabling better resource planning within the profession.

Keywords: accuracy, complexity, estimating, quantity surveying.

INTRODUCTION

The construction industry, in common with all industries, continually strives for progression and development. As Baccarini (1996) and Gidado (1996) have shown, construction has seen spiralling demands for speedier and improved construction, generating far greater levels of complexity. Coupled with this is the need for all parties involved in a project to interact. The financial estimate for a project carried out by the quantity surveyor (QS) is a typical example. The quantity surveying profession is constantly scrutinized, with regular demands for greater accuracy. The question is whether this can be achieved when the complexity of construction projects is constantly growing.

The overall aim of this paper is to assess the impact of project complexity on the accuracy of QSs, with a view to informing decisions about the way that QS practices allocate resources to estimating for projects of differing complexities, and the way that fees are calculated. This involves looking at the accuracy achieved during the estimating and forecasting stages of a construction project and examining projects of varying size and value for new-build office construction in the UK.

The objectives of this paper are fourfold. First, the nature of complexity in the construction industry is established. This involves definition, an insight into the determining factors and a look at its effect on the industry. Second, the paper will

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examine the accuracy achieved by QSs and factors that might influence it. Third, mechanisms for measuring project complexity and QS accuracy are developed. Finally, the effect of project size on complexity is examined.

DEFINING COMPLEXITY

Mohr (1971) considered that complex processes involved tasks not well understood. Others have suggested that only processes comprising innovative operations and conducted in an uncertain situation are complex (Burns and Stalker 1965, Malzio *et al.* 1988). Perrow (1961), on the other hand, defined the complexity of a task as being the degree of difficulty in the search process, in performing the task, the amount of thinking time required and the body of knowledge in existence. Cilliers (1998) pointed out that *if something is too complex to be grasped as a whole, it is divided into manageable units and can be analysed separately and then put together again*. Perhaps, then, complexity is a euphemism for ignorance? In other words, what we do not understand is complex, and after we have grasped the concept, it is simple. Flood and Carson (1988) believed that *in general, we seem to associate complexity with anything which we find difficult to understand.* Vemuri (1978) sees complexity as being *a visualisation of the unfamiliar*.

Weaver (1948) defined complexity as a *sizeable number of factors, which are integrated into one organic whole.* He claimed that complexity is purely a gathering together of relevant variables, which are interrelated into a complicated, but not *helter-skelter* fashion. Complexity, he claimed, *is organized*, making complexity more than simply the number of operations involved in a process (Bennett and Fine 1980) or the size and diversity of tasks (Hill 1991). Indeed there is much support for the view that complexity is closely connected with interaction between components, rather than their sheer number (Pippenger 1978, Yates 1978).

The view that complexity is in the interaction between elements, rather than simply the number of elements, fits well with a picture of the of construction industry consisting of a wide variety of disciplines, each with different objectives and specialisation. Current methods of procurement result in high levels of sub-contracting (Hughes, Gray and Murdoch, 1997), adding to the problems of integrating numerous, diverse organisations.

MEASURING COMPLEXITY

Project complexity is very subjective. Simon (1965) states that the complexity or simplicity of a structure depends critically upon the way it is described. Cilliers (1998), too, acknowledges how the distinction between complex and simple *is not as sharp as some may say*. Practitioners frequently describe their projects as simple or complex, giving credence to the notion that complexity makes a difference to a project (Bennett 1986). There have been attempts to measure construction complexity. For example, Gidado (1996) proposed an approach involving the identification of a number of aspects of project complexity, including the interaction of different parts in the workflow, the number of technologies in a trade and the level of scientific and technical knowledge.

Klir (1985) used systems theory to evaluate complexity by considering its subjectivity. Complexity, he discovered, can be caused by complex systems and complex people. Similarly, systems are complex as a result of the number of parts and number of relationships between these parts (Barrow 1998, Cilliers 1998, Flood and Carson

1988). Rijn (1985) believed that the best way was to compare similar projects and to identify comparable attributes. Melles *et al.* (1990) concluded that a measure of complexity creates a rather significant problem. He believed that this was due to complexity being a significant issue. A common mistake is to equate project cost with complexity, yet management teams are assigned on a percentage basis regardless of complexity levels.

Differentiation, interdependency and integration

Baccarini (1996) showed how complexity could be measured by way of differentiation and interdependency. Differentiation is defined as *the difference in cognitive and emotional orientation amongst managers in different functional departments* (Lawrence and Lorsch 1967). Interdependency, is defined as being *the degree of interrelatedness between these elements* (Walker 1996). These factors are clearly present in any construction project. Technological complexity, in terms of interactions, encompasses interdependencies between tasks, within a network of tasks, between different technologies and between inputs. In his study of complexity in the construction industry Southwell (1997), commented that *differentiation and interdependency are synonymous with the creation of complexity.* Walker (1996) and Hughes (1989) have shown that there are complex interdependencies in construction projects. They have also shown that differentiation in terms of skills or components (technology) is needed according to the complexity of the project's environment. Such diversity represents the amount of technological differentiation, and could be defined as the number of people of different trades or the number of 'work elements'.Such a measure would be well suited to the industry, which in terms of components is well suited to the methods of quantification.

The literature shows that the measurement of complexity is very confused and diverse in nature. The main problem is that there is a lack of effective tools for measuring complexity (Gidado 1996). However, the literature has highlighted two obvious schools of thought. The first of these demonstrates that complexity is the measurement of quantifiable components, with the greater the number of components, the greater the complexity. The second believes that complexity is all about the number of interactions found between such components. However, theories of differentiation, interdependency and integration would suggest that, overall, complexity is the combination of both of these schools of thought, being all about the interaction between high numbers of components.

Complexity in relation to project size

The relationship between complexity and the size of a construction project is very important. Strong links have been proven between size and the level of differentiation (Pugh 1968, Blau 1972), yet the relationship between size and complexity is less clear. A number of studies have examined the issue, producing conflicting results. Child and Mansfield (1972) found a positive link between size and complexity, which was later challenged by Beyer and Trice (1971) and by Dewar and Hage (1978), who said that such a relationship was not provable.

However, as size increases there is no real reason why different specialisms should be added except in terms of administration. Increasing the number of participants does not add to complexity in the same way as increasing the number of skills or technologies. Therefore, just because projects operate on a larger scale, it does not necessarily follow that they will be more complex.

QUANTITY SURVEYORS' ACCURACY

QSs advise their clients on matters of cost. This is particularly crucial at the estimating stage of the project (Ashworth 1999). The aim of the construction price forecast, according to Skitmore (1990), is to provide an estimate of the market for construction projects. However, Ellis and Turner's (1986) survey showed that clients were generally dissatisfied with cost advice. There is an increasing awareness of the need for better accuracy in estimating for construction projects (Skitmore 1985).

It is commonly stated that the difference between an early price estimate and the accepted tender from a contractor represents an inaccuracy (Flanagan and Norman 1983, Morrison 1984, Ashworth 1999). This is by no means the only way in which estimating accuracy has been measured. Morrison and Stevens (1981) and Skitmore (1987), among others, have used the percentage that the forecast differs from the lowest tender.

The results of previous studies looking into the accuracy of construction cost forecasts are contradictory and widely different (Smith 1995). For example, Flanagan and Norman (1983) examined 66 UK projects between 1971-78. Barely a quarter of projects had estimates within 5% of the accepted tender. Bowen and Edwards (1985) discovered that the majority of QSs and architects expect a forecasting error of ±5-6% from the pre-tender estimate. According to Ashworth (1999), accuracy is ±13% on average, depending upon the size of the scheme, the method used and luck. Skitmore (1990) claims that the accuracy of pre-tender estimates will be in the region of ±8%.

Clients feel, quite naturally, aggrieved when they have to produce more finance than was originally planned. Raftery (1984) proposes that the new generation of cost models developed since the 1970s were produced mainly as a reaction to the dissatisfaction that existed with traditional forecasting methods. With accuracy in the region of ±13% (Ashworth 1999) are estimates really worth bothering with and why is it that these costs cannot be forecast at an earlier stage?

Accuracy is always difficult to achieve, for various reasons. Cost data is available from past projects, priced bills, cost analyses and published data, which can result in widely varying estimates. There is a strong tendency to rely on historic costings in the pricing of similar structures. However, Morrison (1984) takes the view that *the largest inaccuracies exist with imperfections in the cost data used and adjustments made to this data to allow for time, location and market conditions.* Perhaps more importantly, the use of cost databases in principle may be wrong, based on the dubious premise that the building's total cost is equal to the sum of its constituent parts. This is simply not the case when issues such as buildability and complexity feature on the list of cost determinants. The technology used in construction processes is also constantly changing.

Proficiency and experience are important factors (Morrison and Stevens 1981, Ashworth and Skitmore 1983, Willis and Ashworth 1987). Ashworth *et al.* (1980) found that many estimators believed that their current methods gave good results, but few could offer hard evidence to support this belief. They concluded that the accuracy of construction estimators is much less satisfactory than most would claim and some estimators are more accurate than others. The reasoning for this lies with experience and judgement, which can only be developed over a period of time (Beeston 1983).

Designs are often incomplete. Information is crucial, as it eliminates uncertainty, and makes cost estimating more reliable (Ashworth and Skitmore 1983). Very often, because of the way the architect works, and the timing of the project, the drawings that go out to tender differ from those the QS uses for the forecast.

Other less obvious factors are also significant, for example, market conditions. A failure on behalf of the QS to read the market conditions will undoubtedly result in poor forecasts (Flanagan and Norman 1983). Pressure is also sometimes brought to bear on the QS to produce a figure acceptable to the client. Such diplomatic cost techniques are, however, very risky and, ultimately, flawed. General external factors influencing the accuracy of an estimate include the level of risk and uncertainty in the project, regional variations, market forces and collusive tendering.

RESEARCH METHOD

The research is limited to one field of construction output, new office construction in southeast England. This involved collecting data on twenty construction projects, randomly chosen from a quantity surveying firm's database. The components of the data for this study were fourfold. First the measure of QS's accuracy, second the measure of complexity, third, the size of a project, and finally a series of interviews were carried out to add depth to the research, and to help explain the quantitative results.

Accuracy

The first stage of the data collection was to measure the accuracy achieved on the projects selected for the study. The method for doing this was an adapted version of the method used by Morrison (1984), Ashworth (1999) and others. It involves comparing the pre-tender estimate produced by the QS with the accepted tender (prior to any post-tender reductions). For comparison purposes, all of the data collected was then set to a common base year, by means of the BCIS tender price index.

Complexity

The second stage of the data collection was to achieve a measure for project complexity. In order to do so, a very longwinded process had to be adopted. After an extensive review of the literature it was clear that the vast majority of studies carried out before had been subjective in nature. A method was therefore formulated based upon the earlier research findings. The method used was to count the number of 'work elements' involved in the project. This was an adaptation of the work carried out by Flood and Carson (1988), Bennett and Fine (1980) and Gidado (1996) and involved the measurement of the number quantifiable components named 'work elements', meaning a process/component of work required as part of a construction project. This did, however, need to be limited to work on site. In fact it was just considered as being the work for a project referred to in the scope of works and specifications conforming with Gidado's (1996) definition of construction work and at the same excluding extraneous variables such as the planning permission, funding and checks such as those by the fire officer. As a result this left constructional, project complexity to be the key issue under investigation, and in particular the 'work elements' carried out on site.

In relation to complexity theory, it was decided that a count of the number of components would, in itself, imply the number of interactions between the components. As the theory demonstrated, when the number of differentiated tasks increases, the need for integration between them grows, as does the number of interactions.

In order to carry out this process, a review of the project documentation was required. For each project the Scope of Works, Architect's Technical Specification, Structural Engineer's Report and the Mechanical & Electrical Specification was acquired. Each was then consulted, and from these the numbers of 'work elements' were extracted. A work element was considered to be a process or component required as part of the construction process. In order to be comprehensive, the categories used in SMM7 were used to provide a structure for the data. Using the project documentation, all work was placed into its relevant SMM7 category. For example, for one of the projects, the piling package consisted of *boring*, *formwork*, *reinforcement*, *concrete pour*, i.e. 4 work elements. Only construction work was counted; any references to materials or strength tests were ignored. This simple count of work elements provided a common basis for comparison across the projects studied. Of course, this approach is highly dependent on how the project is documented and thus, relies to a certain extent on the researcher's judgment as to what should be included in the count. However, since the same researcher collected all of the data, there is comparability between the project reported here.

Size Classification

For the purpose of analysing the data, it was necessary to find a way of categorising the twenty construction projects into a size classification. A cross-section of the firms' employees was asked to provide subjective views about whether projects were small, medium or large. Their responses formed the basis for the size classification of office construction.

Limitations of the Research Method

This research method covers a wide range of parameters, which have focused the study somewhat. As an exploratory study, the aim is not to be definitive. All of the data came from one large quantity surveying practice, providing a control variable in terms of organisational influences. However, this may result in the organisations' policies influencing the data collected. Placing a degree of reliance upon the quality of the specifications and scope of works in each case also placed limits upon the data collection. These specifications, being the only way of accessing the data that was required were an inevitable parameter, and one that could not have easily been avoided.

DATA

As was stated in the research method, once the data had been collected the analysis of that data would require the projects to be classified into size categories. The results of the small survey carried out among employees provide the banding shown in Table 1.

Accuracy

The measure used for the accuracy of a QS's estimate is the percentage deviation between the pre–tender estimate and the accepted tender sum. Table 2 shows the deviation for the twenty projects studied.

In terms of the measure being taken for the accuracy of the QS, the most accurate value that a QS could hope to achieve is zero, where the pre-tender estimate and the accepted tender are equal. However, this is highly unlikely to occur. A positive value in itself is inaccurate, but acceptable, especially from the client's point of view. This is because the accepted tender appears cheaper than the pre-tender estimate. A

Table 1: Project Size Categories

Project Size	Value (£m)
Small	0 - 4.15
Medium	4.15 – 14.8
Large	14.8 +

Table 2: Results

Project	Pre-tender estimate (£m)				
A	5.1	4.78	6.27	891	Medium
B	12.0	12.32	-2.66	935	Medium
C	8.98	8.43	6.12	901	Medium
D	30.0	30.87	-2.90	927	Large
E	0.62	0.58	6.45	743	Small
F	13.15	14.0	-6.46	921	Medium
G	4.70	4.77	-1.49	665	Medium
H	6.8	6.74	0.88	782	Medium
J	4.25	4.18	1.65	900	Medium
K	4.29	4.23	1.40	897	Medium
L	31.0	30.59	1.32	919	Large
M	37.50	37.02	1.28	871	Large
N	2.48	2.23	10.08	820	Small
P	5.26	5.17	1.71	889	Medium
Q	22.5	21.01	6.62	954	Large
R	11.0	11.17	1.55	848	Medium
S	3.29	3.11	5.47	720	Small
T	47.0	47.87	-1.85	933	Large
U	19.08	19.58	-2.63	1062	Large
V	47.0	45.0	4.26	1135	Large

negative value, on the other hand, is the worst value to obtain, indicating a position of under-estimating.

Complexity of projects

The method chosen to obtain a measure of complexity was an arithmetical count of the number of 'work elements' within the project. Table 2 summarizes these totals, in the column headed 'No. of work elements'.

Complexity vs QS accuracy

The aim of this paper was to discover the influence of project complexity upon the level of accuracy achieved by the project's chartered QS during the estimating stage of a construction project. Figure 1 shows this relationship for the data presented in Table 2, along with a line of best fit. The Pearson product moment coefficient is a measure of linear correlation between y and x, which indicates the strength of the relationship between two variables (in this case, *y* is complexity and *x* is QS accuracy) independently of their respective scales of measurement. This produces a value of -0.19. Although Figure 1 appears to show no obvious correlation, the data identifies some interesting points supported by this result, discussed later in the paper.

Complexity vs size

One objective of this paper was to test for a relationship between size and complexity of projects. Using the size classifications from Table 1, the projects are categorized in the last column of Table 2. The frequency that each classification appeared within the twenty projects was then calculated, and an average number of work elements calculated to generate a complexity indicator for each project size (see Figure 2).

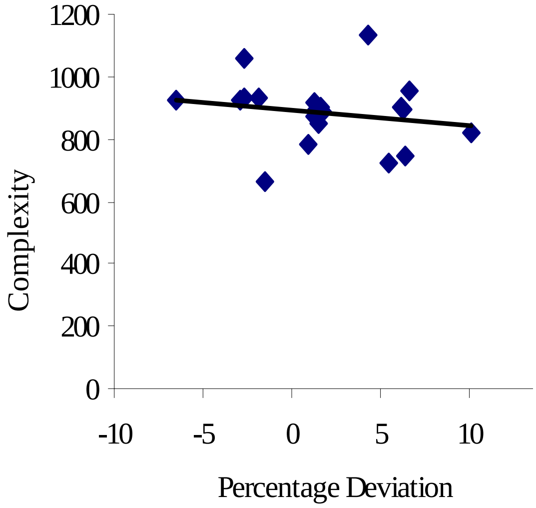

Figure 1: Relationship between complexity and accuracy

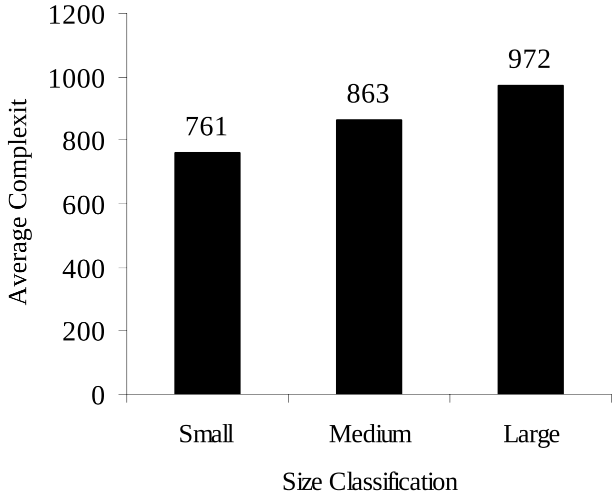

Figure 2: Complexity and size classification

DISCUSSION

Complexity was calculated by assessing the number of elements of work in a project, from a detailed analysis of project documentation. This was based upon the assumption that the greater the number of work elements, the greater the inherent complexity, as a result of an increase in the number of interfaces between these elements. The data in Table 2 show complexity ranging from 665 work elements to 1135. It must be pointed out that, although the complexity measure involved a thorough study of all of the individual project specifications, these specifications were each prepared by different organisations and had no standard layout or structure to them. This may have resulted in slight inaccuracies in the work elements for each project.

Estimating accuracy

In analysing the figures for accuracy, some descriptive statistics are helpful: a mean of 3.65, a range of 9.2, a standard deviation of 2.61 and a coefficient of variation of 71.5%. The standard deviation is quite high for such a mean, indicating a wide spread of results. This is supported by the value for the coefficient of variation, at 71.5%, also indicating a large spread in the data set. The range of estimating accuracy stands at 9.2. For a sample of just twenty projects, randomly chosen, this appears to be quite a wide divergence amongst the data. The lowest forecast was -6.5% (i.e. lower than the accepted tender), and the highest forecast was 10% more than the accepted tender. However, in comparison to the literature reported earlier in this paper, the figures for QS accuracy do not appear to be particularly bad.

The method of measurement used to calculate the estimating accuracy is a relatively common means of judging accuracy. However, the pre-tender estimate is, to a certain extent, unique to the circumstances of each project. Although it is the QS's final estimate for a project prior to tender, the state of the project at this point may well influence the accuracy achieved. For example, one project may have a more fully developed design and specification than the other. That project will, as a result, be easier to forecast than one less well specified. It is also worth considering that the accepted tender sum, against which the pre-tender estimate was compared, is very often not the lowest tender received. A number of factors influence the selection of a contractor, not just the estimated cost. In turn this would influence the accuracy, as measured here. Another point worth some consideration is that there are additional factors influencing the QS's accuracy.

All of the data sources used in the study were collected from one large quantity surveying practice. Therefore, although the data used for the accuracy measure would have provided some form of project constant it may well have been biased or influenced in some way, by the firm's policies or culture. It may be, for example, that as an organisation they always forecast the pre-tender estimate a little high, to allow for any errors in their work, or unexpected tender returns.

The relationship between complexity and accuracy

At first sight the relationship between the level of project complexity and the accuracy of the QS looks negligible. As shown in Figure 1, the data was widely scattered and would apparently show no obvious correlation. However, once a line of best fit is applied the relationship between the two variables becomes clearer and a slight negative correlation is seen. This would suggest that the lower the level of project complexity, the greater the accuracy of the QS. However, because of the nature of the measure taken for quantity surveying accuracy, the percentage deviation is more difficult to explain.

If 0% deviation is the best achievable by the QS it can be seen that along the line of best fit the negative percentage deviation has a higher value of project complexity. However, the positive percentage deviation has a lower value for project complexity. Therefore, one could state that (in terms of the negative correlation created by the best fit line) the higher the complexity, the greater the negative (adverse) percentage deviation. In contrast as the level of complexity declines, the percentage deviation improves until it reaches 0% and enters into a positive deviation and a level of 'acceptable' inaccuracy.

Although the data set in this relationship appears to be wide ranging and well spread, 13 of the 20 projects studied are on or very close to the line of best fit, with only a few rogue points

The relationship between complexity and size

Using classifications of size developed from the sample survey of employees, the results show seven large projects, ten medium-sized projects and three small projects. This is a good spread, considering that the selection of projects was random. The relationship found between project complexity and project size is strong. Figure 2 shows a very clear positive correlation between complexity and size. In other words, as the size of the project increases, so too does the complexity of that project. Consequently the results support the findings made by Child and Mansfield (1972) who stated that a positive link could be identified between size and complexity. It is not clear why this is so. Just because a project is larger in size does not necessarily mean that it is any more complex. It could simply be the case that the scale of the project is greater. However, it may be assumed that greater size will result in a greater need for co-ordination and management of the technological elements that make up the project. In turn this will result in a greater number of interfaces between the work elements and, hence, mounting complexity.

CONCLUSIONS

Preparing a working definition of complexity remains an elusive concept. Complexity is being a subject that is still so new and wide ranging that nobody knows quite how to define it, or even where the boundaries of it truly lie (Waldrop 1992). The relatively straightforward measure used here for the calculation of complexity was developed from a number of past studies. The results indicate that the measurement of complexity may be better indicated by the way that the various work elements interact, especially since complexity is understood to be a result of the combination of many interrelated parts.

Although the measure of quantity surveying accuracy was acceptable and justifiably supported as being so by previous academic studies (Ashworth 1999, Morrison 1984) there is a need for a definition of estimating accuracy. Conflicting definitions create confusion in the measurement of accuracy. This in itself is crucial to resolve if progress is to be made in the QS profession. Without a measure of the estimators' achievements, improvements cannot be made. The ability to do this may result in greater cost control and improved cost performance within the industry, while bolstering the reputation of the profession.

Although the findings cannot state categorically that any relationship exists between the accuracy of a QS and the level of project complexity, the findings suggest that there is such a relationship. Conclusive results were produced as to the relationship between the level of project complexity and the size of a project. The data showed a direct, positive correlation, suggesting that as the size of a project grows, so too does the complexity. The only reservation with this result is the question of whether the same result would have been generated with alternative measures of project size and over a wider sample of projects.

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