THE MANAGEMENT OF CONSTRUCTION FAILURES AND DEFECTS

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Recent developments in research into the avoidance of accidents and failures in several industries has placed emphasis on managerial forces influencing the event rather than the actions of an individual error perpetrator. Similar research into managerial forces related to lesser construction failures is, however, notable by its absence. This paper reports a study of 23 housing projects constructed by two house-building companies in the UK. A statistical analysis was conducted of "individual", "managerial" and "external" factors compared with dependent variables of cost, times and levels of defects for the projects. Significant relationships were not generally noted between factors and dependent variables, with one important exception. There was a correlation between the senior managers 'a priori' ratings for their site managers and out-turn project performance. This supports the commonly held intuitive view that project performance (whether related to cost, time, defects or accidents) depends on the individual quality of key workers, in this case the site manager. The implications of this finding are that efforts to reduce defects should focus on managerial selection, training and education, rather than interventions of the "quality systems" type.

Keywords: Construction failure, defects, human error, project management

INTRODUCTION

"The experience with non-marine structures indicates that the challenge of reducing human and organisational error in design and construction is not a problem of not knowing what to do. It is primarily a problem of not doing what we know we should not do".

This quotation, taken from a report for the United States Ship Structures Committee by Robert Bea (1994), encapsulates the dilemma faced by technologists attempting to reduce the incidents of failures, defects and accidents in all industries. The technology is well known, yet problems still arise (HSE 1976). In support of this dilemma is the view that human error predominates in failures and accidents. This view, long held in the high risk nuclear (ACSNI 1993), chemical (Kletz 1985) and transportation (Lourens 1990) industries is being taken up in civil engineering (Eldukair and Ayyub 1991, Ellingwood 1987). Its relevance to relatively minor failures including construction defects has been noted (Rollings and Rollings 1991, Stewart 1995), but has yet to be applied to building projects, as opposed to civil engineering.

Following close behind recognition of the importance of the human component in failure is the view that managerial influences are behind many errors. This view is expressed from the perspectives of psychology (Reason 1990), sociology (Turner 1978) and engineering (Petroski 1985, Blockley 1992). Driving the emphasis on managerial factors is the view that human errors are, to a certain extent, inevitable and should be allowed for in complex processes (Reason 1990, Brown and Xiaochen Yin

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1988). Several authors make a simple distinction between “active” and “latent” errors, the latent error often being a managerial failure predisposing a system to failure. From this distinction is developed more complex hierarchical models of failure or accident causation (Embrey 1992, Harrison 1992, Eldukair and Ayyub 1991, Whittington et al 1992). For example, Eldukair and Ayyub (1991), divide the causes of failures into primary and secondary, the former covering the technical cause of failure, the latter the managerial reasons for failure. Whittington et al (1992), in the context of construction accidents, propose model of accident causation which operates at four levels, <u>company policy</u>, <u>project management</u>, <u>site management</u> and the <u>individual</u>.

Although the influence of “management” is recognised by these authors, little work has been done to systematically identify the detailed <u>content</u> of the managerial component as applied to construction projects and to defects and failures <u>in the finished product</u>. Indeed, many authors, including those from both psychology (Rasmussen 1983, Reason 1990) and sociology (Perrow 1984) stop short of specific recommendations and resort to bland exhortation. It is necessary to turn to the fields of technology (Petroski 1985, 1994), reliability engineering (Embrey 1992), forensic engineering (Kaminetzky 1991) and major interdisciplinary studies (ACSNI 1993, Bea 1994) to uncover detailed managerial causes leading to the failure of projects. These common themes are confirmed, by examining literature from project management (Morris 1994) and quality management (Oakland 1993), disciplines directed towards avoiding the causes identified.

PREVIOUS RESEARCH

A systematic review of the literature and preliminary confirmation of managerial factors driving errors related to projects was undertaken as prior research to that reviewed here and is reported in detail in Atkinson (1997). A three level model of the error process in project systems, based on the literature, was proposed and tested by conducting a questionnaire survey of 107 construction industry practitioners. The results confirmed that the range of factors identified in the model was reasonably robust, with some modifications. There were some suggestions that error prevention is a “team” effort and has “socio-technical”, or “systemic” characteristics and there was a strong indication in open responses that factors loosely termed “managerial” (covering aspects such as leadership and motivation) were considered important. Factor analysis suggested that factors loaded on three underlying groups and the findings from the survey led to the construction of a modified model of the error process. This model, summarised below, formed the basis of a more detailed study of the influence of the individual factors and interactions between them.

MODIFIED MODEL OF THE ERROR PROCESS

Primary factors

- Skills of tradespeople (Representing knowledge acquisition, training, education and experience of selected operatives)

Managerial factors

- Checking, inspection and control
- Division of responsibilities
- Control of changes
- Control of concurrency
- Communications
- Culture of the organisation

External factors

- Cost
- Time
- Societal pressure

THE STUDY

Although earlier work had confirmed the importance of several factors in the model, the mechanism underlying both the operation of factors and systemic interactions between them had yet to be examined. Additionally, the previous study had sought opinions on the relative importance of factors, but objective measurement of their influence on performance had not been attempted. In pursuing further work in this area, it was considered that direct methods of investigation were likely to be most appropriate. Thus, much research consisted of soliciting information, particularly as to the cause of errors, by using interviews and participant observation techniques. However, it was also considered that statistical measurement of performance and comparison with measures related to factors in the model was possible. The overall design of the study, therefore, consisted of a combination of interview, ethnographic and statistical methods. It is the statistical study which is reported here.

Object

The object of the study was to investigate whether there was any statistically significant relationship between factors in the model and the performance of construction projects. In addition, literature suggests that performance might depend on the interaction of several variables in a systemic manner. Statistical analysis attempted to uncover these interactions.

Method

A representative sample of construction projects was sought in order to compare factors in the model with performance in terms of defects, costs and times. Practicalities of conducting the research restricted the sample to UK projects, and availability of projects further restricted the sample to the south-east and midlands areas within the UK. Projects involving buildings of a similar scale and using a similar construction type were sought in order to control as far as possible for extraneous variables related to complexity of construction and differences in the characteristics of participants. Speculative housing construction in the UK tends to use a relatively similar pattern of procurement and construction, therefore, simple two or three storey speculative housing projects were targeted. As the subject matter of the research was potentially sensitive, involving data on defects, costs, construction timing and errors, random selection of participants was rejected. Rather, direct contact was made with four house-builders and a total of four regional offices of two of these house-builders agreed to take part in the study. Both house-builders were well organised, involved in "volume" production and "premium" rated by building guarantee insurance companies. Although they cannot be considered as representative of house-builders as a whole and in particular of smaller, less formally organised companies, they do represent the larger established companies, which construct the bulk of speculative housing in Britain. A total of 23 housing projects were included and data was primarily collected verbally in an interview with the site manager for each project. Some data, mainly related to costs and programmes, were collected from other personnel in the companies. Data were recorded on a two part structured interview form, the first part being completed in the presence of the site manager and the second part (recording details of construction and standards of finished work) being completed at the end of the visit by the researcher.

Identification of variables

Variables were identified, corresponding to the factors in the model, but at the same time the opportunity was taken to identify additional variables thought to have a bearing on the research in general. Thus, a larger set of both independent and dependent variables were identified than strictly required.

Independent variables

Primary factors

The site manager was asked to rate the skills of the tradespeople for each trade working on the site and this rating was later converted to an average score for the site. In addition, in order to assess the influence of primary factors related to the site manager on performance, the site manager was asked for an estimate of the number of years experience he/she had in the industry and as a site manager. Also data on the background (trades/management) and formal qualifications (qualified/unqualified) of the manager were collected.

Managerial factors

Communications

For informal communications, the site manager was asked how many contacts were made by non-line staff per month. For formal communications, the site manager was asked to rate the quality of the project documents on their volume, clarity and buildability. The rating was later converted to a score. Further data on formal communications were sought by asking whether the designers were in-house or consultants.

Culture

On the basis of literature equating culture of organisations with the extent of managerial participation (Oakland 1993, ACSNI 1993, Turner 1978), the site manager was asked how many contacts were made with line managers, how many formal company meetings he/she attended and how many sub-contractor meetings he/she held. The sum of contacts and meetings was used as a score representing cultural aspects.

Division of responsibilities, control of concurrency and control of change
These factors were combined into one overall “planning” factor for the purposes of statistical analysis on the basis of findings in the earlier study and literature on project management (Morris 1994). Earlier research (Hinze and Raboud 1988) had also suggested a link between planning and construction safety and the opportunity was taken to attempt to replicate this finding related to other performance measures. Site managers were asked how work was planned in three aspects, method (informally, bar chart, CPA), location (central, local) and extent of updating (updated, not updated). For analysis purposes, these divisions were reduced to two - centrally planned and locally plus centrally planned.

Checking and supervision
The site manager was asked to indicate how he/she checked the work of each sub-contractor, in terms of frequency and level of formality. No usable objective data was obtained from this question and it was excluded from the analysis (in contrast, the question provided a rich source of qualitative data not reported here).

External factors
Economic/cost pressures
The site manager was asked whether the site was pressurised in terms of cost (tight/not tight)

Time pressure
The site manager was asked whether the site was pressurised in terms of time (tight/not tight)

Societal pressure
The site manager was asked whether the quality of the project had been affected by societal pressure, but no usable objective data was obtained from this question.

Other independent variables
Certain other information, not directly related to the model, was collected as either a check on the presence of confounding variables, as possible proxies for other factors or because the information was volunteered.

Tidiness of the site
Data on the tidiness of the site were collected by direct inspection by the researcher on three categories, tidy, untidy and normal.

Developer and developer by region
It was possible to easily categorise data into the two firms and four regions involved in the study. This could act as a check on the presence of confounding variables, in particular efficiencies or inefficiencies of production based on company differences. One region was located in the midlands of the UK, with the other three in the south-east or London area and analysis by region allowed locational differences to be examined.

Manager rating

The managing director for one region of one company made available an assessment (based on the views of senior managers) of the site managers for the region on a scale of 1-10. The opportunity was taken to see whether the assessments correlated with any objective measure used in the study.

Derived independent variables

Several of the above variables were combined to form composite derived variables, or were collapsed from continuous to categorical variables. The objective in this was to allow a systems effect (in the form of statistical interactions between categorical variables) to be examined by using Analysis of Variance. Variables so formed were:-

- Trade skill level (high/low)(collapsed from “skills of tradespeople”)
- Manager’s experience level (experienced/inexperienced) (collapsed from “experience of manager”)
- Project management score (continuous variable) and project management level (high/low)(collapsed from “project management score”). The score was constructed by taking the product of scores for planning ,informal and formal communications and culture.
- External influences score (continuous variable) and external influences level (strong/weak)(collapsed from “external influences score”). The score was constructed by taking the product of the scores for cost pressures, time pressures and an index of the complexity of construction.
- Culture and informal communications score (continuous variable) and participation level (high/low)(collapsed from “culture and informal communications score”). The score (for “soft” communications) was constructed by taking the product of scores for informal communications and culture.

Dependent variables

A measure for the level of defects on the sites was sought, but was impossible to accurately obtain. Rather than obtain direct measures of the level of defects, therefore, it was decided to collect information for multiple dependent variables thus:-

- A subjective quality assessment of the site made by the site manager, scored on the questionnaire for comparison with independent variables.
- A rating of the quality of the site made by the researcher.
- A record of the number of defects verbally reported by the site manager weighted to reflect the extent to which the site was complete.
- The rate of construction in square feet per week. Given that all regions were “premium rated” by building guarantee insurance companies and should have relatively equal performance in relation to defects, faster construction produces <u>less defects per unit constructed per time period</u>. In other words, **speed** acts as a <u>proxy</u> for defects.
- The cost of construction per square foot allowing for locational and complexity differences between sites. In a similar way to faster construction giving a relatively lower level of defects, <u>cheaper construction gives a lower level of defects per unit value constructed</u> and **costs** acts as a <u>proxy</u> for defects.

SUMMARY OF STATISTICAL TESTS

Correlation analysis (Pearson) was used in comparing dependent variables with continuous independent variables (trade skills, site manager's experience, informal communications, formal communications, culture, project management score, external influences score, participation score and the senior managers' ratings of site managers). Independent samples t-tests were used in comparing dependent variables with categorical independent variables (site managers' qualifications, site managers' background, planning regime, cost pressure, time pressure). One way analysis of variance was used where repeated tests were made with the same variables (tidiness of site, designer differences, company differences) and two way analysis of variance was used in comparing dependent variables with some selected pairs of categorical independent variables (trades skills level/managers experience level, trades skills level/project management level, trades skills level/external influence level, trades skills level/culture and informal communications level, external influence level/culture and informal communications level, manager's experience level/project management level, manager's experience level/culture and informal communications level, project management level/external influence level).

The formal hypotheses were that there would be no significant correlations, differences, main or interaction effects between independent and dependent variables.

RESULTS

The overall results of these statistical tests gave little support for the contention that any one factor (or interaction of factors), as represented by the independent variables in the set has a clear influence on the performance of the sites as represented by the dependent variables. For a clear influence to be shown, it would be expected that an independent variable would show a significant (at or near $p<0.10$) correlation or difference when compared with a minimum of two or three dependent variables. The results indicated, rather, a distribution of probabilities with a random scattering of significant results, occurring, in themselves, at a relatively low frequency. However, there were some interesting exceptions to these disappointing, if not entirely unexpected, results and these are reported as follows:-

- Trade skills were significantly ($p<0.05$) correlated with the site manager's own quality rating.
- The score for culture was loosely ($p<0.10$) correlated with both the researcher supplied inspection rating and costs. This correlation was, however, "perverse" in that both dependent variables showed a better performance with a lower score for culture!
- The score for external influences was significantly correlated with costs ($p<0.05$), but again the correlation was "perverse" and lower costs were associated with stronger external influences.
- The ratings of site managers by senior management (for one region only of one company) was significantly related to the rate of construction (positively @ $p=0.07$) and costs (negatively @ $p=0.033$)).

DISCUSSION

The results demonstrate some of the difficulties in using statistical techniques in conducting field research in project management. The null hypothesis cannot be rejected for most links between independent and dependent variables, but, given the weight of literature and previous research supporting the existence of links, one is left with the feeling that the results do not tell the whole story.

Working within the methodology of this study, reasons for a general lack of links are not hard to find. The sample size of 23 was small and consisted of projects from two organisations having a very similar profile - large conglomerate house-builders, both "premium" rated by building guarantee companies. It would, perhaps, have improved the results if a larger sample of projects from smaller and less well rated companies had been obtained. Unfortunately, access to such organisations, given the nature of the information required, was not forthcoming.

The target dependent variable measure was the level of "defects", but this measure is difficult to obtain. Defects have both a **numerical** component and a **seriousness** component, confounding any straight summing. Additionally, a defect, once detected is corrected and this leads to temporal problems of measurement - does one count them during construction or after, when several may be hidden, forgotten or corrected. Even the cost of correcting defects, which both organisations systematically collected, proved misleading as a measure because costs would variously be lost in the initial construction costs, charged back to sub-contractors or revealed in the maintenance budgets. Using total cost and construction times as a proxy for the defects rate was thought more reliable, but again differences in construction type confounded costs and required adjustments. The pace of construction was often deliberately adjusted to the sales rate, also leading to the need for adjustments. That such adjustments and measurement problems led to inaccuracies was evidenced in tests **between** dependent variables, where good correlations were generally obtained, but probably not close enough to avoid confounding the analysis. Some measures of independent variable, for example for the level of checking, were impossible to obtain and some might be criticised for not reflecting what they were supposed to be measuring (for example, is culture adequately measured by the level of line communications?).

The "perversity" of several results, where they were significant, but in the wrong direction, suggests the operation of confounding variables. Statistical analysis alone is unable to provide clues to what these variables could be, but other methods and common sense could be used to fill the gaps. Thus, common sense suggests that an inverse relationship between culture (measured as the level of line communications) and performance, would be conditioned by the skills of the site manager, the complexity of the site or the stage of construction.

Nevertheless, the results from the study, when combined with conclusions elsewhere do provide two interesting and consistent conclusions. Firstly, the suggestion that relationships between some factors and dependent variables, which are **inverse** to that expected, is supported by interviews with the site managers for the 23 sites and more senior managers. These interviews are not reported here, but many managers indicated that contact both with line managers and non-line managers were dependent on the complexity of the site and the experience and skills of the site manager. This indicates the contingency nature of much project management and is consistent with research elsewhere (Barratt 1989).

Secondly, the significant relationship between the primary skills of the tradespeople and a quality rating and the significant relationship between senior managers ratings of their site managers and measures of cost and time, suggest that primary skills are more important than indicated in earlier research. The relationship between ratings of the skills of tradespeople and quality must be considered somewhat suspect, as the site manager provided both ratings (although separated by several pages on a questionnaire). However, senior managers' ratings of site managers were <u>independent and predictive</u>. The ratings were given in advance of knowledge of the performance of the sites in terms of speed and cost of construction and they were not linked to the qualifications, experience or background of the site manager (which were all separately tested and found not to be significant).

The fact that senior managers were able to identify accurately good performers, suggests that some individual quality of the site manager is salient in achieving good performance of the project. This is consistent with qualitative responses in the earlier research reported above (Atkinson 1997), where several respondents referred to leadership. It is also consistent with the commonly expressed intuitive view that project performance (whether related to cost, time, defects or accidents) depends on the individual quality of key workers, in this case the site manager. The implications of this finding are that efforts to reduce defects should focus on the performance of the individual in the form of managerial selection, training and education, rather that interventions of the "quality systems" type. This parallels suggestions by Seymour and Low (1990), relating to the quality assurance movement applied to construction, that the movement inappropriately depersonalises responsibility for performance and de-emphasises such individually based concepts such as care, integrity and morality.

CONCLUSIONS

The difficulties experienced in using statistically based research into project management means that it should be used with care. However, provided that the limitations in sampling, constructing variables and handling intervening variables are recognised, there is logically no reason why the method should not be used. Unfortunately, it is clear that much research fails to recognise the limitations of statistics and obscures or ignores the problems.

It remains likely that successfully and adequately providing all the conditions for statistical analysis in project management research will prove impossible. This means that the technique should only be used in association with other, more direct, methods of research. This problem was recognised in the current work and this study forms part of a larger programme, which combines direct enquiry with statistics and will eventually use triangulation (Miles and Huberman 1994) in drawing overall conclusions.

For the present study, however, it must be left that the statistical analysis suggests that, of the factors identified in the model, it is the primary factors, but related to the site manager, that have the clearest relationship to project performance.

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