IT'S NOT JUST ABOUT BRICKS AND MORTAR: PROCEDURAL FAILURES IN CONSTRUCTION

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Construction and engineering projects are typically complex in nature and are prone to cost and schedule overruns. A significant factor that often contributes to these overruns is rework. Omissions errors, in particular, have been found to account for as much as 38% of the total rework costs experienced. To date there has been limited research that has sought to determine the underlying factors that contribute to omission errors in construction and engineering projects. Using data derived from 59 in-depth interviews undertaken with various project participants, a generic systemic causal model of the key factors that contributed to omission errors is presented. The developed causal model can improve understanding of the archetypal nature and underlying dynamics of omission errors.

Keywords: causal modelling, error, omission, rework.

INTRODUCTION

Design changes, errors and omissions account for 79% of the total rework costs experienced in a project but of this percentage, omissions errors account for 38% (Willis and Willis, 1996). Omissions errors can be defined as failures to follow due procedure when undertaking a task(s). These are the single most common form of human error (Reason, 2002). Specifically, projects appear to progress smoothly until nearing completion, when such errors made earlier are discovered, necessitating costly rework. Such rework transpires as overtime, additional hiring of resources (including labour and plant), schedule slippage, and reductions in project scope or quality. The adverse consequences of these difficulties include reduced profit, loss of market share and reputation, increased turnover of management and workforce, lower productivity, higher costs, and, all too frequently, costly litigation between participants over responsibility for overruns and delays.

There has been a considerable amount of research that has examined the nature of human errors, its types and causes in a range of areas such as aviation (e.g. Amalberti and Wioland, 1997), medicine (e.g. Reason, 1995), engineering design (e.g. Busby, 2001) and construction (e.g. Atkinson, 1998), yet studies that explore the underlying conditions and factors that contribute to the occurrence of omission errors are limited. Using data derived from 59 in-depth interviews undertaken with various participants operating in the construction and resource engineering sector a generic causal model of omission errors is developed.

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CAUSES OF ERROR

Errors occur due to physiological and psychological limitations of humans (Helmreich, 2000). It is a matter of contention whether individuals can justifiably be blamed for all errors, as making mistakes is an innate characteristic of human nature (Reason, 1990). Human errors occur for various reasons and therefore different actions are needed to prevent or avoid the different sorts of error experienced in construction and resource engineering projects. Regardless of the skill level, experience or training that individuals possess, errors and omissions may be made at any time.

Reason (1995) proffered that there is no one error taxonomy that can be used for all circumstances as different error classifications serve different needs. Despite Reason's (1995) assertion, several classification schemes however have been put forward for identifying generic causes of error (e.g. Andi and Minato, 2004) and are deemed useful for assessing potential risks in projects. For example, Rogge *et al.* (2001) developed a tool to provide early warning of possible rework prior to construction, based on the underlying conditions that could contribute to its occurrence. Such conditions include the degree of design coordination that is undertaken, the extent of design schedule compression, and the regularity of engineering verifications. Similarly, Manavazhi (2004) developed a probabilistic model that could be used to forecast the propensity of a project to encounter design revisions. Design revisions are an inevitable and integral feature of the design process therefore, it is important that firms are able to put mechanisms in place to plan and manage them as they occur. Design revisions that require rework arise due to errors, incomplete misinformation, and changes (e.g. those that are client initiated and unforeseen) and can have detrimental effect on productivity, morale, designer attitudes and the overall profitability of the design practice. An error can arise due a number of reasons:

Mistake
An error occurs as a result of ignorance of the correct task or the correct way to perform it. Reason (1995) suggests that such mistakes can be either rule- or knowledge based. With respect to rule-based errors, a practitioner may simply misapply a rule that is has worked in a previous situation because they failed to notice contraindications. Alternatively, a bad rule that has remained uncorrected in a practitioner's collection of problem solutions could be applied to the situation at hand. Knowledge based mistakes occur when the practitioner encounters a novel situation that lies outside the range of their learnt problem solving routines. Kletz (1985) refers to such mistakes as a mismatch, as they arise because they are beyond the physical or mental capability of an individual. When confronted with such a position, practitioners are often forced to resort to slow and effortful reasoning and as such susceptible to making errors (Reason, 1995). This is because a practitioner can only attend to and manipulate one or two discrete items at a given time, and they have to reply on a mental model of the current situation that is inherently incomplete (Reason, 1995). In addition, practitioners have a tendency to follow their instinct and select features of the world to support it, while neglecting contradictory evidence that presents itself before them.

Non-compliance
An error occurs because an individual decides not to carry out a task or not to carry it out the way instructed or expected. They are deliberate acts and may occur due to motivational problems (e.g. low morale, poor supervision, perceived lack of concern,

etc). Such errors occur in a regulated social context and the prevention of which must be addressed through motivational and organisational remedies vis-à-vis improving the quality and delivery of information within an organisation and project.

Slips and lapses of attention
*A*n error that occurs as a result of forgetfulness, habit, or similar psychological issues. Here the error typically occurs at the level of execution and generally involves routine tasks in familiar surroundings. Reason (1995) suggests such errors are associated with some form of attention capture, either distraction from the immediate surroundings or a preoccupation with something.

Omission errors arise when the mental process of action-control is subjected strain or distraction (Reason, 2002). Action control involves at least four stages, planning, intention storage, execution, and monitoring, and a problem in anyone of these processes may lead to an omission occurring (Table 1).

Table 1: Processes involved in omitting a necessary step (Reason, 2002)

Level of Failure	Nature of Failure	Failure Type
Planning and intention formation	A necessary item is unwittingly overlooked. The item is deliberately left out of the action plan	Mistake Violation
Intention storage in prospective memory	The intention to carry out the action(s) is not recalled at the appropriate time	Lapse
Action execution	The actions do not proceed as intended and a necessary item is unwittingly omitted from the sequence	Slip
Monitoring	The actor neither detects nor corrects the prior omission	Slip or violation

Determining the exact cognitive processes that are involved in omitting a crucial task is an arduous process, as even the error maker finds it difficult to identify the cause of a specific failure. Reason (2002) suggests that to reduce the incidence of omission errors in a process, there needs to be a shift away from examining the underlying mental processes involved to those characteristics most likely to afford them. Several authors have identified a number of task properties that are likely to increase the probability that a particular task in a process will be omitted, for example:

- the greater the informational loading of a particular task, that is, items within a step are more likely to be omitted when the demands imposed upon short term memory are higher (Norman, 1998);
- procedural steps that are functionally isolated, that is, ones that are not obviously cued by preceding actions nor follow in a direct linear succession from are more likely to be left out (Reason, 2002);
- recursive or repeated procedural steps are particularly prone to omission. In the case where two similar steps are required to achieve a particular goal, it is the second of these two steps that is most likely to be neglected (Herrman *et al.*, 1992);
- steps in which the item to be acted is concealed is liable to omission (Reason, 2002);
- steps located near the end of a task sequence are likely to be omitted. Such premature exits are due in part to the actors preoccupation with the next task, particularly when the current activity involves largely routine tasks (Reason, 1998); and

- tasks that involve planned departures from standard operating procedures or from habitual action sequences are liable to strong intrusions in which the currently intended actions are supplanted by a more frequently used routine in that context, and thus omitted (Reason, 2002).

A number of the above omissions may occur simultaneously and be combined into a single task. When this happens, the effects are additive and the result is a recurrent error trap for those involved (Reason, 1998).

RESEARCH APPROACH

To determine the latent conditions that contribute to omission errors an exploratory research approach was adopted. This was because limited research pertaining to the causal ascription of omission errors has been undertaken within the domain of construction and resource engineering projects. Causal modelling, an inherent feature of system dynamics, was used to construct a systemic causal model of omission errors. Causal modelling can be used to provide managers with the necessary insights about the inter-dependencies and behaviour between key variables that can contribute to omissions so that learning and process improvements can be made to future projects.

Data collection

Fifty nine in-depth interviews were conducted over a six month period with a variety of personnel such as operations managers, project managers, engineering managers, architects from the construction and resource engineering sector (Table 2). Interviews were used as the mechanism to determine the causal nature of omission errors. Interviews were chosen as the primary data collection mechanism because they are an effective tool for learning about matters that cannot be observed. According to Taylor and Bogdan (1984:p.79), no other method "can provide the detailed understanding that comes from directly observing people and listening to what they have to say at the scene". Construction and resource engineering firms from Melbourne, Perth, and Sydney were selectively sampled and invited to participate in the research so as to reduce the likelihood of duplicating experiences from the same project. Firms in the Top 20 for construction and resource engineering by turnover as per the Dun and Bradsheet listing were identified and those where the research team had a direct contact point were invited to participate in the research. The interviews were conducted at the offices of interviewees. Interviews were tape recorded and transcribed verbatim to allow for the nuances in the interview to be apparent in the text. The interviewees' details were coded to allow for anonymity, although all interviewees were aware that it might be possible to identify them from the content of the text. The format of the interviews was kept as consistent as possible following the themes associated with rework identified from the literature. Interviews were kept open using phrases such as 'tell me about it' or 'can you give me an example'. The open nature of the questions allowed for avenues of interest to be pursued as they arose without introducing bias in the response. Notes were taken during the interview to support the tapes to maintain validity. Each of the interviews varied in length from 45 minutes to two hours. Interviews were open to stimulate conversation and breakdown any barriers that may have existed between the interviewer and interviewee.

Data analysis

The text derived from the interviews was analysed using QSR N5 (which is a version of NUD*IST and combines the efficient management of Non-numerical Unstructured Data with powerful processes of Indexing and Theorising) and enabled the development of themes to be identified. One advantage of such software is that it enables additional data sources and journal notes to be incorporated into the analysis. The development and re-assessment of themes as analysis progresses accords with the calls for avoiding confining data to pre-determined sets of categories (Silverman, 2001). Kvale (1996) suggests that ad hoc methods for generating meaning enable the researcher access to 'a variety of common-sense approaches to interview text using an interplay of techniques such as noting patterns, seeing plausibility, making comparisons etc' (p.204). Using NUD*IST enabled the researchers to develop an organic approach to coding as it enabled triggers or categories of interest in the text to be coded and used to keep track of emerging and developing ideas (Kvale, 1996). These codings can be modified, integrated or migrated as the analysis progresses and the generation of reports, using Boolean search, facilitates the recognition of conflicts and contradictions. This process enabled the development of a causal model. Reason's (2002) classification of 'failure types' (i.e. mistake, violation, lapse, slip) was used to determine the reason for the occurrence of an omission error (Table 1). The interviews revealed insights about participants and their experiences associated with omission errors in projects. Table 2 presents a summary of interviewees sampled by industry sector. From the interviews a total of 85 omission error cases were derived from the interviewees' comments.

Error categorisation

Table 3 presents examples of omission errors and the respective failure type. It can be seen that 53 (62%) of errors were due to practice, 11 (13%) task, 5 (6%) circumstance, 11 (13%) convention and 5 (6%) tool. An example of a violation was undertaking a peer-review of design documentation for internal purposes so as to reduce risk and not to examine how the mechanical engineering design married with the project's structural elements (Table 4). This practice not only results in the review process being ineffective but is likely to lead designers into a false sense of security and perhaps aberrant to self checking. An array of practices contributes to the occurrence of an omission error. The practice of designing work based on tentative information, departing from established procedures and under estimating the time for engineering design are common conditions with which design firms are typically confronted with.

Table 2. Sample characteristics by position and industry sector

	Industry Sector		
Position Type	**Oil & Gas (n=20)**	**Mining (n=18)**	**Construction (n=21)**
Operations Manager	2	2	-
Project Manager	12	4	5
Structural Engineer	3	3	4
Procurement Manager	-	2	-
Quantity Surveyor	1	-	4
Architect	-	-	8
Mechanical Engineer	2	5	-
Engineering Manager	-	2	-

The effects of adopting such practices can lead to higher demands being placed project personnel (e.g. stress and anxiety), conflict and naturally, increased project time and cost. In terms of tasks, the causes of omissions related to designers and project personnel being placed under increasing pressure to complete their tasks within a specified time frame. Unrealistic demands and constraints were deemed to have been imposed on project personnel, which often resulted in tasks being ‘unwittingly’ overlooked or omitted from a pre-determined sequence. For example, in Table 4, project personnel were confused about whose role it was to order materials. This situation arose because the engineering manager had not confirmed with the procurement personnel the required specification for some off-shore equipment that was required. Without the confirmation no order could be placed. Yet, the procurement personnel simply forgot to follow-up with the engineering manager and without checking assumed that an order had been placed.

Many of the underlying conditions that contribute to an omission are interdependent and in many instances isolating a specific causal variable proved difficult (Table 4). The issue of design fees was identified by interviewees in the construction sector as a factor contributing to an omission and design related rework. Lower design fees juxtaposed with a ‘stretched’ design and documentation schedule invariably resulted in tasks such design reviews, checks, and verification being omitted. Moreover, to maximise fees and save design time existing design details and specification are reused, which may result in having a design that is inappropriate for its intended purpose.

Table 3 identifies an example of an omission error and how it was classified in terms of failure type. Of the 85 omission cases identified, violations accounted for 51 (60%) slips 14 (16%), lapses 13 (15%) and mistakes 7 (8%). Many of the violations identified were simply committed with the intention of increasing operational efficiency. Firms cannot and should not tolerate disregard for established procedures. The consequences of following such a course of action could be disastrous, not only in terms of increased project costs and time but areas of safety and design integrity. There are several compelling reasons for this. One is, of course, that standardisation of operations cannot be achieved with idiosyncratic adherence to procedures.

Table 3: Omission errors identified

		Quantity		
Omission Error Cause Examples	**Failure Type (e.g)**	**Oil & Gas (n=28)**	**Mining (n=26)**	**Construction (n=31)**
Failure to undertake design reviews	Violation	19	17	17
Distribution of tentative design documents	Violation			
Engineer failed to detect and corrects an omission in design documentation	Slip	2	5	4
Schedule pressure resulted in disproportionate time allocation for tasks	Violation			
Low design fees meant tasks were deliberately left out	Violation	2	1	2
Schedule pressure result in some tasks not being recalled at the appropriate time	Lapse			
Re-use of existing specification and design solutions	Violation	4	2	5
Failure to adhere to new company polices	Violation			
Inoperability with CAD software applications (no checking for inconsistencies)	Violation	1	1	3
Simplification of tasks and neglect for other aspects of design	Slip			

Causal model of omission errors

A detailed analysis of the interview data enabled the researchers to determine the archetypal nature and underlying dynamics of errors and thus develop a systemic causal model (Figure 1). Figure 1 identifies the conditions that can promote an active failure to arise. Client requirements and the fees and margins of designers, consultants and contractors were issues that influenced the planning and resource allocation and the subsequent workload of individuals of individuals. More often than not in projects, individuals and teams are given excessive workloads that require them to work longer hours in order to meet schedule. Consequently, individuals are subjected to increased levels of workplace stress and subjected to information overload which can affect short term memory of individuals (Table 4). This can result in a task deviation occurring through a lapse or slip. Procedures such as checking are simply overlooked or not given the due attention that is required when pressure to ‘get the job done’ is exerted. Views from respondents revealed that it is often taken for granted that if there are ‘omissions’ and they cannot be readily detected then they will be picked up later in the project. The longer an error goes undetected the likelihood of significant rework occurring increases which can impact cost and schedule.

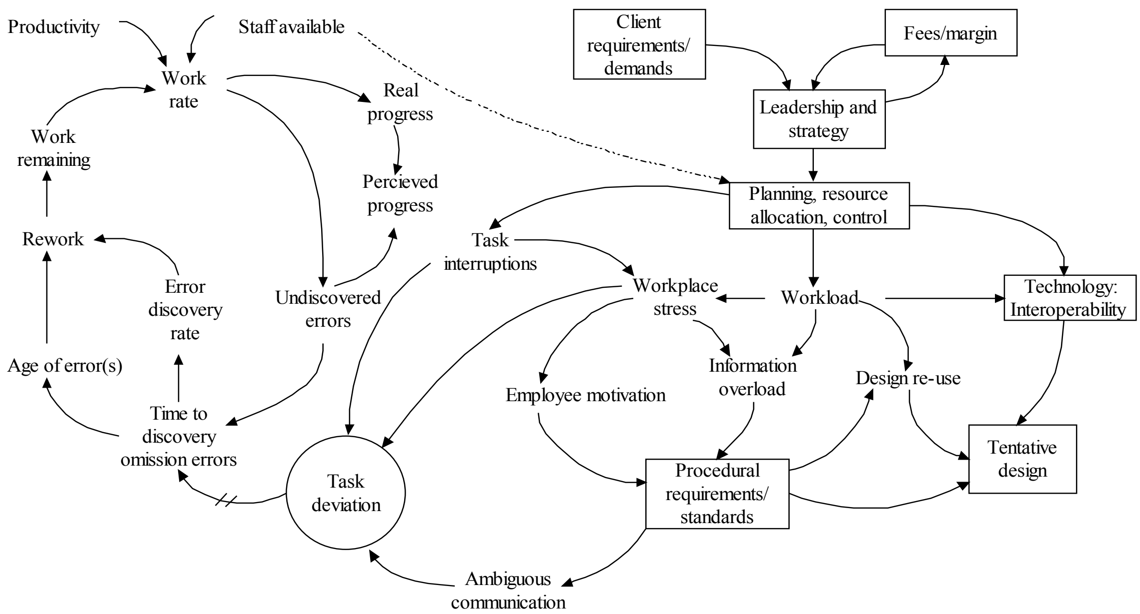

Figure 1: Systemic causal model of omission errors

An engineering manager suggested that a parochial attitude of ‘she’ll be right’ was prevalent in many projects and thus contributed to the establishment of complacency. This was also identified as occurring in several instances by project managers on-site in construction and resource projects. Another interviewee stated that some engineers on-site often do not adhere to company quality procedures/standards and fail to complete the required documentation. Only when non-compliance is issued or an audit is undertaken that they begin to do what they are supposed to do. Then after a period, the engineers on-site tend to go back to their original modus operandi. It was suggested by the project manager that some form of penalty could be issued for continually adhering to non-complaint practices or some form of educational programme explaining why procedural compliance was necessary should be undertaken.

Table 4: Examples of omission errors

Omission Error Type	Interviewee Comment
Informational overloading Task sequence omitted Procedural steps that are functionally isolated	"For detailed design you have to pay lump sum for certain parts of the design. There is always a lot of pressure on the consultants to be competitive either through minimum target man-hours, or through the man-hour rates. Consultants tend to recover that by increasing scope through claiming for changes in the design. They often "take short cuts" when they feel they are not getting a good fee. If they work on a lump sum basis there is always a lot of pressure on total number of man hours required to do the work and if they need more man hours, then as they have to deliver within the lump sum so their way to save money is by reducing what they pay their people. It is only under fully reimbursable type of contract where you can take that kind of pressure away. You need some idea how much a project is going to cost you – the cost of blank cheque approach is high to clients".
Informational overloading	"Well…a number of reasons….If you look at where we are today we are almost 70% of the way through the project, running almost 10% behind. The reason for the delay [is] late placement of purchase orders for some materials, late delivery of some materials; somebody forgot to place an order or assumed someone else going to do it. Engineering is progressing on track and if you look at the work off-shore, we're also behind work off-shore. The reason we are behind work off-shore is due to errors and the subsequent rework".
Task sequence omitted	"But in practice you don't have time to do that, it's just not possible, as you try to meet the schedule, and so you end up taking some short cuts …..You compromise if you like"
Task sequence omitted Procedural steps that are functionally isolated	"We carry peer reviews etc at various stages during design and also during construction. However, when schedule (perhaps due to a major re-design) becomes critical we sometimes skip these stages and try to manage the subsequent risks that could arise. When we do peer reviews we bring someone in who is external to the project that has the right level of experience to sit down and review the proposal and making sure that based on their experience it all appears to be logical and sensible as to where we are going. In my experience though there have been times when the peer-review has not worked – they tend to gloss over and often blinded by their own experience".
Informational overloading Task sequence omitted	"You get errors because there is a misunderstanding (or lack of knowledge) by the fabricator of the design. Not that the design is wrong but the way the fabricator reads the design information might be different from the way the designer meant it to be. In this case, we were under pressure to finish a number tasks, and certain things were 'basic' items had been missed off the drawings and we expected the fabricator to pick this up – he didn't. It was our fault really

When projects are subjected to fast-tracking (overlapping of design and construction activities) it was found that the re-use of design details and specifications by architects, and engineers were approaches used to minimise their workload and the production of a tentative design. This can lead to incomplete information with regard to design. The effects of having tentative design information are compounded further when organisations use differing technology and software applications that are partly incompatible (interoperability). Simple, pragmatic considerations such as checking for design inconsistencies are overlooked due to an 'unhealthy' over-reliance on the software applications output. Ambiguous communication such as not providing clear direction and information on what, when and how a task is to be completed can result in tasks being omitted. This was clearly the case in the example presented in Table 4, when there was a misunderstanding about the late placement of purchase orders.

Interruptions to tasks being undertaken due to rework, design changes, or sequencing of tasks may result in an individual forgetting what they were supposed to do and skip particular steps because they have been delayed.

CONCLUSION

Omission errors are a problematic issue in construction and resource engineering projects. The competitive environment within which firms operate often results in short cuts and procedural tasks being neglected in order to achieve the demands being imposed on them. Organisations and individuals tend to repeat such practices because they become complacent as there appear to be no direct consequences for their actions. Even when errors do arise, there appears to be no transfer of learning from previous experiences. This is because organisations operating in a project environment are subject to new demands and constraints by different client organisations. The causal model that has been presented can be used to provide project managers with a better understanding the omission affording features inherent to projects and therefore aid them in identifying and implementing error containment and reduction strategies. The caveat to this is that no one strategy is a panacea for reducing omissions, but focusing on the reduction of violations and adhering to procedures and protocols is the first step that is required in this instance.

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