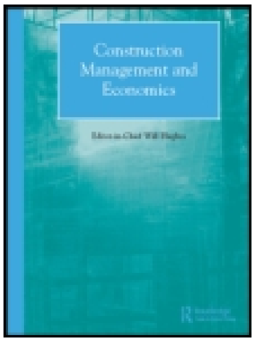

Construction Management & Economics

ISSN: 0144-6193 (Print) 1466-433X (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

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To cite this article: P. E. D. LOVE , P. MANDAL & H. LI (1999) Determining the causal structure of rework influences in construction, Construction Management & Economics, 17:4, 505-517, DOI: 10.1080/014461999371420

To link to this article: https://doi.org/10.1080/014461999371420

Published online: 21 Oct 2010.

Construction Management and Economics (1999) **17**, 505–517

Determining the causal structure of rework influences in construction

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Received 10 November 1997; accepted 18 May 1998

One of the most perplexing issues facing organizations in the construction industry is their inability to become quality focused. As a result sub-standard products and services often emanate, which inadvertently result in rework. Typically, rework is caused by errors made during the design process. These errors appear downstream in the procurement process and therefore have a negative impact on a project's performance. The lack of attention to quality, especially during the design process, has meant that rework has become an inevitable feature of the procurement process, and the costs have been found to be as high as 12.4% of total project costs. Such costs could be even higher because they do not represent schedule delays, litigation costs and other intangible costs of poor quality. To reduce the cost and effect of rework, an understanding of its causal structure is needed so that effective prevention strategies can be identified and the effects of rework reduced or eliminated. A case study approach based upon deductive and inductive reasoning is used to identify the major factors that influence rework in projects. From the findings and with reference to recent literature, the concept of system dynamics is used to develop a series of influence diagrams, which are then integrated to develop a conceptual causal loop model that is used to determine the overall causal structure of rework. Once an understanding of the causal structure of rework events has been acquired, effective strategies for rework prevention can be designed and implemented in order to improve project performance. This paper contributes to study of quality in construction by capturing the complexity and dynamism of those factors that influence rework and project performance in a holistic manner.

Keywords: Quality management, rework, system dynamics, causal loop diagramming

Introduction

During the last decade practitioners and researchers have focused on managing quality in organizations in an attempt to improve their overall performance and competitiveness. Well-known quality gurus such as Crosby (1984), Ishikawa (1985), Deming (1986) and Juran (1988), have made substantial contributions to the development of quality concepts and practices. The present quality revolution has been fuelled by increased global competition and many companies have accepted the challenge of improving their quality of service and products by implementing total quality management (TQM).

The implementation of a TQM philosophy can help a company improve its productivity, and both customer and employee satisfaction. The strategic benefits of implementing TQM programmes may contribute to a greater market share, as well as lower costs, and improve productivity (Phillips *et al.*, 1983). Total quality management is a philosophy that is based on a particular way of thinking, working and organizing, which is recognized by all persons in the organization as well as its external partners. This philosophy is profit orientated, customer-focused, people-focused, partner assisted and environmentally conscious. Total quality management establishes quality throughout all levels of the organization.

In construction, however, one of the most perplexing issues facing companies is their inability to become quality focused (Jaafari, 1996). The international quality standard ISO 8402 defines 'quality' as the totality of characteristics of a product, process, organization, person, activity or system that bear on its ability to satisfy stated and implicit needs. Tucker *et al.* (1996) found that construction companies have embarked on the quality journey because of an Australian government mandate that insists that companies must be quality assured (QA) to an internationally recognized standard (e.g., ISO 9000) to be eligible for government contracts. Assurance to such standards provides proof that an optimal level of quality is being obtained throughout all stages of the product's quality cycle. It is an overall system of monitoring activities and mechanisms that aims to prevent quality deviations and to give early warning of poor quality, from the design of the product to its delivery and use by the customer (Kelada, 1992).

Most construction companies that become accredited to ISO 9000 (or equivalent) are expected to supply services or products that will meet the expectations of the customer. However, QA is typically viewed as no more than an administrative-based burden and no dialogue is conducted with users of the product or service (Jaafari, 1996). Consequently, frequently the *status quo* of poor quality often prevails. Moreover, the associated costs of QA have been found to be both an encumbrance financially and culturally to many companies (Jaafari, 1996). As a result, companies eschew progressing to implement continuous improvement and TQM principles (Love *et al.*, 1998a).

Becoming quality assured is the first step in the pursuit of quality. For QA to work effectively it needs to operate within a TQM environment (Burati *et al.*, 1989). In other words, QA is merely a technical inspection and surveillance procedure that is just one of the components of a company-wide application of TQM. Because companies cannot see the benefits of becoming quality focused, often substandard products and services emanate, which inadvertently result in rework.

Rework occurs when a product or service does not meet the requirements of the customer. Consequently, the product is altered in accordance with customers' requirements. With this in mind, rework includes defects and may also include variation. Similarly, CIDA (1995) defines rework as "doing something at least one extra time due to non-conformance to requirements". No organization participating in a project produces a substandard product or poorly performs a service intentionally; nevertheless, we tend to accept it as part of human nature. Even when there is a profound and genuine conviction to quality, it is not necessarily achieved. For a building to be procured not only does it have to be produced to a desired quality, but it has to be constructed and delivered on time, in the right market, and at minimum cost.

Organizations operating in a project environment find it difficult to fulfil simultaneous objectives. More often quality is sacrificed or compromised to meet other objectives. Every participating organization and individual may affect the final quality of the product or service, as quality is every participant's business. A construction project can be likened to a chain that is only as strong as its weakest link. When the weak links are not quality-focused, deviations in quality may occur, which result in rework. Research to date has been limited to identifying the causes and effects of rework in construction (e.g., Cnuddle, 1991; Hammarlund and Josephson, 1991; Burati *et al.*, 1992). A fundamental problem with identifying cause and effects is that it does not examine the relationship between process activities. In fact, frequently such an approach is applied when a problem occurs, and rarely applied as a means to determine the effects of process changes. To identify in any great depth the influence rework has on project performance its causal structure must be identified. There have been limited attempts to determine the causal structure of rework influences in construction. Causal models have been applied to a number of other situations, for example the influence of different management subsystems on productivity (Shaddad and Pilcher, 1984), the application of expectancy theory of human motivation (Maloney and Fillen, 1985), and the factors influencing productivity levels (Borcherding *et al.*, 1986).

This paper builds on previous work undertaken by Cnuddle (1991), Hammarlund and Josephson (1991) and Burati *et al.* (1992) by determining the causal structure of rework influences and identifying those major variables that stimulate its occurrence. The first section of this paper identifies rework as a product of waste. This is followed by the research methodology and a description of two case study projects used to identify, in conjunction with the literature, the major factors that influence rework in projects from a systems perspective. The findings are used to develop a series of influence diagrams and a causal loop model, based on the concept of system dynamics, to determine the relationships between the causes of rework and its effect on project performance. By modelling rework in the project system it will help construction professionals improve their understanding of a project system. It is envisaged that understanding will stimulate the identification of effective prevention strategies that can be implemented to improve project performance. This paper contributes to the study of quality in construction by identifying factors that stimulate rework and therefore affect project performance.

Rework is waste

To improve quality it is necessary to understand the *root causes* of rework, that is, the basic reason for its existence or set of conditions that stimulate its occurrence in a process. A process consists of a number of activities or operations which acting on inputs in a given sequence transform them into outputs. A process may consist of both value adding or non-value adding activities. The former are activities that convert materials and/or information towards that which is required by the customer and the latter are activities that take time, resources or require storage and do not add value to the final output. In other words, a non-value adding activity is waste. According to Koskela (1992, p.35) there has never been any systematic attempt to observe all wastes in the construction process. Koskela (1992) suggests that the figures that have been presented tend to be conservative inasmuch as the motivation to estimate and share these figures has been by leading companies that have been attempting to implement best practice.

Rework, however, has become an accepted part of the construction process. Those involved in the procurement of buildings invariably do not realize the extent of rework that actually occurs. There is an increasing need to improve the quality of operations throughout the procurement process, and therefore reduce the incidence of rework. It has been suggested that the major cause of rework is uncertainty (Bowen, 1992; Koskela, 1992; Laufer, 1997). This uncertainty is generated by poor information, which often is missing, unreliable, inaccurate, and conflicting. (Koskela and Huovila, 1997). The authors suggest that uncertainty is a consequence of numerous interrelated factors and not solely information. Therefore to reduce rework we must identify what its causes are, then understand how these causes are interrelated (Rodrigues and Bowers, 1996).

A systematic view of rework

To understand the internal mechanisms of rework in a project one should look at the project activities from a systems perspective (Rodrigues and Bowers, 1996; Williams *et al.*, 1996). Such a perspective provides a fundamental shift in thinking and encourages rework problems to be visualized in a holistic manner (Checkland, 1981; Rodrigues and Bowers, 1996). By adopting a systems perspective the interdependenceand links amongst different components of a system can be explored. Based upon the work of Evans and Lindsay (1996) and Mandal *et al.* (1998) a project system can be categorized as being comprised of the following sub-systems:

- technical and operational,
- human resources, and
- quality management.

By applying this categorization to construction, a process model of the elements that could influence rework in a project has been developed, as illustrated in Figure 1.

The major items or elements that need to be considered in a technical/operational sub-system are the procurement method, operating environment, technical support and the technology. These items influence quality-related issues such as the recognition of customer needs, process improvement, and partnering/strategic alliances. The major elements of a human resources sub-system are manpower, employee morale, skill availability, and communication procedures. These elements to a large extent determine training needs, skill level, employee motivation and the decision-making process in both a construction and project organization. Explicitly, the three sub-systems are interdependent. Figure 1, however, does not provide the following details.

- How does one factor relate to another? For example, how is communication related to motivation. Is there any relationship between these variables at all?
- What are the internal mechanisms by which a particular factor causes a change in other factor? For example, we know poor communication (and lack of coordination) leads to higher rework (CIDA, 1995). But how? What are the mechanisms by which the lack of coordination ultimately results in higher rework?
- How does an affected factor cause change in such a way that the former input factor

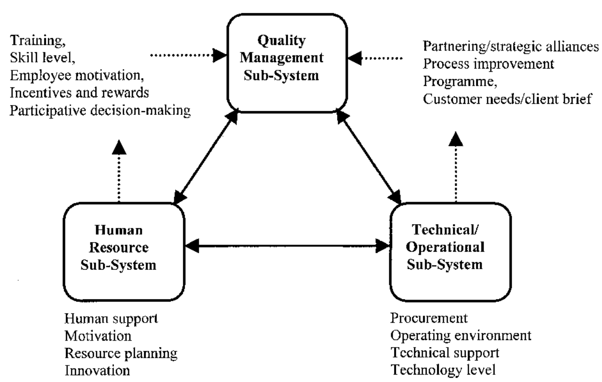

Figure 1. Interactions amongst the three sub-systems of a project

ultimately gets affected? Poor communication leads to higher rework, but higher rework may eventually force improvements in communication.

Causal loop diagrams or influence diagrams, as advocated through the application of a systems dynamics methodology, can provide explanations to these questions.

System dynamics

System dynamics has its own paradigm and has established itself as a powerful methodology (Mohapatra and Mandal, 1989). The modelling process is iterative, though the stages to be followed may appear to be sequential. Implicitly, Mohapatra *et al.* (1994) suggest that system dynamics can fulfil certain modelling requirements, especially in the context of rework. These include a holistic view of the rework phenomena, construction of causal relationships, identification of feedback mechanisms, and searching for explanations in behaviour (Rodrigues and Bowers, 1996; Williams *et al.*, 1996). The primary focus in system dynamics is the examination of the effect that one element has on another. System dynamics as a modelling tool can be used to identify variables that need to be improved so that rework can be reduced or eliminated (Rodrigues and Bowers, 1996; Williams *et al.*, 1996).

The technique of causal loop diagramming is used in this paper to provide the platform for linking the major causal variables of rework. A causal loop diagram can show explicitly the direction and type of causality among the major factors, which is fundamental in understanding rework in a project system. It can be used to model the influences of inputs on outputs and vice-versa. (If variable A is causing a change in variable B, the direction of causaility is from A to B. If an increase (decrease) in variable A leads to increase (decrease) in variable B then the type of causality is positive. Otherwise it is negative.)

Senge (1990) has undertaken interesting work in the area of causal relations. Senge has used the concept of the causal loop to show why certain process patterns develop over time, and theorizes that there are patterns of causal behaviour (or archetypes), that can explain why events happen in certain ways. For example, one archetype defined by Senge (1990) is the 'vicious circle'. This is interpreted as 'A implies an increase in B, which implies an increase in A which implies an increase in B . . .' and so on. In order to understand the inner mechanism and behaviour of rework events there is a need for a degree of experimentation. Such experimentation is not considered to be easy to implement due to the complex and dynamic nature of projects.

In this paper the justifications for relationships are supported by findings from the two case studies and the literature. There are, however, a number of ways to justify causal links, such as direct observation, reliance on accepted theory, hypothesis or assumption, and statistical evidence (Coyle, 1977). The research methodology is described next.

Research methodology

The seminal paper of Seymour and Rooke (1995) without doubt has encouraged academics in the field of construction management and engineering to re-think their approaches to research. They suggested that much of the research that has been undertaken in the construction management and engineering field to date has been formulated on deductive theory-testing research methods. Such methods often are based upon the scientific process of deduction typified by the formulation of theories followed by the deduction of empirical consequences from large samples, and the observation of their validity. More recently, however, there has been a trend towards inductive research methods, which typically are used for relatively underdeveloped theoretical constructs or where complex observation is required. Such interpretative research methods have been advocated by numerous researchers in the field of the social sciences, such as Giddens (1976), Pettigew, (1985), Romano (1989), Parke (1993).

Authors that support the use of interpretative research, such as case studies, participant observation, and ethnography, argue that deductive reasoning and analysis have contributed to most theories not being informed by data (Perry and Coote, 1994). In other words deductive theory testing research methods do not adequately capture the complexity and dynamism of the context of organizational settings (Coyle, 1977). In the example of a case study methodology, this approach may lead to a more informed basis for theory development (Yin, 1984).

A case study can provide analytical rather than purely statistical generalizations. Thus 'theory' can be defined as a set of concepts and generalizations. A theory can provide a perspective and a way of seeing an interpretation which ultimately leads to understanding some phenomenon (Agar, 1986).

In the case of the research presented in this paper, that phenomenon is rework. If a purely inductive approach to the research problem were adopted existing theory would not be taken into consideration. Under the inductivist banner knowledge gained through the process of socialization influences the formulation of hypotheses (Zikmund, 1988). However, purely inductivist statements are "inevitably theory-laden" (Chalmers, 1976). In fact, Glasser and Strauss (1967, p.253) state that it is difficult to ignore previous theory accrued in one's mind before commencing the research process. Research that relies solely on deduction would presumably not emerge with a new and useful theory. Parke (1993, p.256) argues that "both extremes are untenable and unnecessary and the process of on-going theory advancement requires continuous interplay between the two so as to lessen the gap between know and knowable". Furthermore, Miles and Huberman (1984, p.134) state that "induction and deduction are dialectical and not mutually exclusive research approaches". Thus, prior theory can provide guidance on the types of data to be collected so that the causal variables of rework can be derived. Prior theory can be used also to interpret research findings. In fact, existing theory derived from the literature will form the basis for generalizations.

A case study can take a deductive or inductive approach to a research problem. For example, the research of Walker (1994) investigated the time performance of buildings based on predetermined hypothesis testing, and its external validity through the use of statistical measures, demonstrates the use of deductive inquiry. However, Bresnen (1986), who researched the organization of projects and matrix management, placed emphasis on theory building and internally validating his research question through information richness, coherence and insight from triangulated sources. The approach taken by Bresnen demonstrates clearly the use of an interpretative inquiry.

With this in mind, the present research sought to obtain a balance between deductive (theory) and inductive (fact) reasoning by using a case study approach. Such an approach can be used to provoke concepts and generalizations pertaining to rework causes, and therefore stimulate the development of a causal model of rework influences. Concepts, generalizations and interpretations that are derived from the case study can be used for assisting management in their practical decision-making (Chentiz and Swanson, 1986).

Cases

Each project case described here indicates clearly its unique characteristics, especially in the context of the contractual arrangements implemented. Eisenhardt (1989, p. 537) supports the use of cases that are polar or of a unique nature. Furthermore, Eisenhardt contends that cases that are selected randomly are considered to be neither necessary, nor even preferable (Eisenhardt, 1989, p. 537). In this instance, however, the projects were selected on pragmatic considerations, namely their availability. There is no ideal number of cases that should be undertaken (Yin, 1984). Similarly Romano (1989) suggests that the number used should be left up to the individual researcher. By contrast, however, Lincoln and Guba (1986) and Eisenhardt (1989) suggest that cases should be used until theoretical saturation or to the point of redundancy which, as Perry and Coote (1994) highlight, neglects time and money constraints.

Two project cases were used to determine the causal influences of rework.

Project A – which consisted of two 6-storey residential apartment blocks containing a total of 43 units. Underground parking, a landscaped podium and a swimming pool are among the facilities incorporated in this development. The contract value for the development was A$10.96 million, with a contract period of 43 weeks (Table 1). The project was procured using a traditional lump sum contract, with the client employing a project manager to act as their development representative. The role of the client's project manager was to administer, integrate and coordinate the consultants and contractor.

Project B – which consisted of a 2-storey industrial warehouse, solvent store and book repository. The contract value for the development was A$4.45 million, with a contract period of 30 weeks (Table 1). The project was a negotiated document and construct contract with a guaranteed maximum price and savings participation incentive. A project manager was employed by the client to act as their representative. A conceptual design was developed and the contractor took responsibility for documenting and constructing the facility.

Table 1. Project details

Project detail	Project A Residential development	Project B Industrial development
Original contract period	43 weeks	30 weeks
Extension of time	5 weeks	8 weeks
Original contract value	A$10 960 000	A$4 450 000
Revised contract value	A$12 065 900	A$4 769 333
Variations (Client initiated changes)	A$806 356	A$319 333
Rework – variations (Direct costs)	A$299 544	–
Rework – Non-variations (Indirect costs)	A$40 960	A$64 078
Rework – non-conformance	–	–
Rework – defects (Indirect costs)	A$5000	A$42 905

Personal contact was established with senior management within the contracting organization to explain the nature and purpose of the research and to acquire background information on the projects. This process was then repeated with site management staff and other project participants. A full guarantee of confidentiality and anonymity was given, and the independence and neutrality of the researchers was stressed.

Data collection

Data were collected from the date from which construction commenced on site until the completion of the defects liability period. Interviews (unstructured and semi-structured) were conducted with each project's client, site management team, consultants, subcontractors and suppliers. Each of the projects described was visited three times a week throughout their duration. Two block visits of four days to each project were conducted. These block visits were undertaken during times of increased site activity. Subcontractors were interviewed at the work face or in their site offices to obtain additional detail relating to rework events. Interviews were used primarily to determine those variables that influenced the occurrence of rework. Coyle (1977) supports such an approach for establishing causal relationships. The interviews were conducted on a one-to-one basis and were open so as to stimulate conversation and breakdown any barriers that may have existed between the interviewer and interviewee. The interviewee was allowed to talk freely without interruption or intervention, so as to acquire a clear picture of their perspective.

Interviews were used to gain (Easterby-Smith *et al.*, 1991):(1) an understanding of the constructs that the interviewee uses as a basis for forming opinions and beliefs about a particular rework event; (2) an understanding of the step-by-step logic of why and how a rework event occurred; and (3) the confidence of the interviewee, to overcome the reluctance to be truthful about an issue other than through confidentially in a one-to-one situation.

Direct observations, and documentary sources provided by the contractor, consultants, subcontractor and suppliers were used also to derive data. Numerous other sources such as variation lists, site instructions, daywork sheets, extension of time claims and nonconformances were used also to identify rework events and determine any effect on project performance in terms of time and cost. Such an approach to data collection is commonly referred to as 'triangulation' (Todd, 1979).

Gathered data pertaining to rework incidents were categorized according to their cause, trade, and effect on overall project time and cost. A summary of these findings can be found in Love *et al.* (1998b). The direct cost of rework for project A and project B was found to be 3.15% and 2.40% of the original contract value, respectively. Davis and Ledbetter (1989), who found the costs of poor quality to be 12.4% of total contract value, had undertaken similar research. Also Josephson and Hammarlund (1996) found the costs of defects in construction projects ranged from 2.2% to 9.0% of total project cost.

The major variables that influenced rework in both projects were identified from the interviews with the clients, project managers, architects (and recent literature) and used to derive influence diagrams. These diagrams were then combined to produce a conceptual causal loop model. The findings from the case study are used to derive a series of influence diagrams, which are presented in the next section.

Findings and discussion

System dynamics models are used to study systems that display feedback characteristics (Mohapatra *et al.*, 1994). Therefore, it is considered appropriate that the study of the causal relations should be conceptualized as series of influence and causal loop diagrams.

An influence diagram simply depicts a succession of causations so that all variables are both causal and affected variables. Essentially, this means that cause and effect relationships can be traced by following the direction of the arrows, starting from any one variable, traversing the loop and coming back to the same variable. Such circular cause and effect relationships provide the foundation for building a system dynamics model. The nature of the modelling indicates that it would be impractical to expect quantitative data with respect to all variables identified (Mohapatra and Mandal, 1989). Therefore, interpreting the variables may be considered to be subjective.

Technical and operational influence diagram

The technical and operational sub-system relates to the structural and functional elements of the procurement process (Figure 1). The important considerations identified from the interviews were categorized in accordance with Figure 1, that is, procurement method, programme and client brief. Figure 2 provides a summary of those factors found from the interviews and literature that influence rework in the technical and operational system.

It can be seen in Table 1 that there were no significant differences between the costs of rework in project A and project B; however, there were some significant

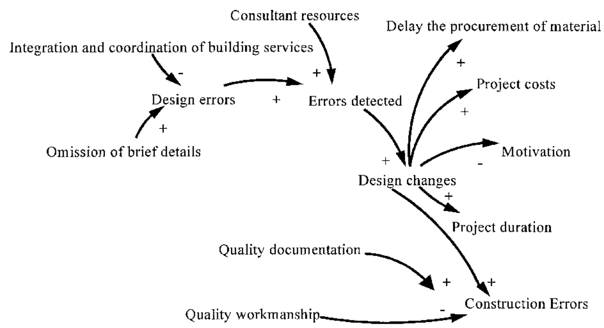

Figure 2. Major influencing factors of rework in the technical and operational sub-system

differences in their causes. In project A, it was found that rework was predominantly attributable to design errors and changes, whereas, in project B rework was caused mainly by construction errors, originating from poor detailing and workmanship. Research conducted by Hammarlund and Josephson (1991) supports the causes identified in both projects.

Interviews with the contractor, subcontractors and end-users revealed that omissions from the project brief led to design errors being detected downstream in both projects. In project A, for example, participants were not coordinated and integrated effectively, despite the use of an independent project manager. The architect substantially developed the design before the design engineers were selected. As a result, little attention was given to the mechanical, electrical and hydraulic services of the building. The lack of attention to coordinating and integrating the building services with the architectural drawings contributed to design errors. Information contained within the contract documents was consistently inaccurate, conflicting, and incomplete. Both the architect and engineers stated that the programme they were given was unrealistic inasmuch as they were given only limited time periods to prepare the project's contract documentation. In fact, they suggested that they did not have the resources available to complete the documentation sufficiently as their fee was based on the concept brief and as a result the scope for error detection was low. They further suggested that they had only allocated so many hours per week to the project, and did not realize the true extent of the work to be undertaken as the brief given to them was evolving simultaneously with the design. To complicate the design process the project manager sold the apartments off the plan as the design was developing. As a result, purchasers requested changes, which naturally affected the design programme and resulted in rework. Strict time and cost parameters were established because interest charges being incurred by the client were considered to be extremely high.

Design changes as a result of error detection during construction were common occurrences in both projects. In project A, for example, the contractor asked the project manager on numerous occasions for a design freeze as the changes were effecting programme, project cost and motivation of site management and subcontractors. A design freeze was not granted and as a result extensions of time of 5 weeks were granted. Koskela and Huovila (1997) suggest that a design freeze should be applied as early as possible so that rework could be minimized. A design freeze would have been effective only if the concept and project brief were developed by a highly skilled professional who could have taken control of the design process and then communicated the clients requirements to all participants involved.

The lack of attention to quality by consultants was costly in time and money. Site management spent up to 30–35 hours a week for the first 10 weeks of the project checking the architectural, structural and service drawings to ensure that dimensions, etc., coincided with one another. When errors were found the designers had to re-design and re-schedule the necessary elements. Notably, the designers did not use any form of computer aided design: they solely relied on the traditional manual system of preparing contract documentation. The use of a convenient and common platform for information transfer and exchange could have reduced their rework significantly.

A substantial amount of rework occurred in project A because the entire mechanical exhaust system for the basement car park had to be re-designed: it did not comply with the building code. The dimensions of the architectural drawings for the basement differed significantly between section, elevation and plan. The foreman noticed these errors within two days of being on site. The basement excavation was about to commence, and this subsequently allowed the design team to correct their errors without affecting the project's critical path.

In some cases, however, the costs of errors were considerable. For example, in project A errors and missing dimensions significantly affected the setout of the building. Setout drawings had to be re-drawn at an additional cost of A$37 500. Hammarlund and Josephson (1991) had identified similar problems associated with setout as a consequence of poor coordination. Problems associated with coordination and integration are chronic symptoms of the traditional lump sum methods used for procuring projects (CIDA, 1995), as demonstrated in project A.

In both projects the contractor waited over three weeks for the architect and structural engineers to coordinate and approve the 'shop drawings' for the procurement of structural steel. This delay had a negative impact upon the contractor's programme and required certain elements of the projects to be rescheduled. Again, the architect and structural engineer in project A and B stated that they did not have the resources available to check and approve the shop drawings any quicker. A symptom of low design fees had meant they only allocated so many hours per week to each project they undertook. As both projects progressed the design consultants blamed low design fees for any errors made in the documentation. They stressed that the scheduled programme and lack of resources prohibited them from producing fully documented working drawings. The contractor identified discrepancies in the documentation. Accordingly, those problems that arose were solved on site. This was a time consuming process for the contractor and increased the incidence of rework and non-productive time.

The uncertainty and poor quality of the documentation delayed the procurement of materials and contributed to the creation of 'walls' between the contractor and the designers, which inadvertently affected communication and stimulated conflict. For example, in project A it was found that both the architect and engineer had overlooked the building regulations and eschewed coordinating their drawings during the design process. The pitch of the roof was changed and this required a major re-design. This delayed the fabrication of structural steel for the roof by 6 weeks, and as a result the contractor had to re-programme major elements of the project. The draftsman raised over 90 requests for information (RFIs) relating to the geometry of the roof. Answers to most RFIs took more than two weeks. Consequently, this meant that those preparing the 'shop drawings' were given limited time to produce functional 'shop drawings'. Staff had to work overtime and additional resources had to be employed. This had a negative affect on other projects being undertaken by the office. The draftsman estimated the cost to generate each RFI was A$90 and took approximately one hour to prepare. The estimated cost of correcting the shop drawings was A$16 000. This sum included the indirect costs of two contracts worth A$3000 and A$5000.

Rework was generated from different phases of each project's development process. Most of the rework experienced, however, was generated from the conception and design stages of the projects. Fundamentally, a lack of understanding and incorrect interpretation of customer requirements, inadequate resources, design errors, and errors in the drawings or specifications juxtaposed with poor coordination and integration resulted in rework being experienced. Koskela (1992, p.35) suggests that it "sometimes seems that the wastes caused by design are larger than the cost of design itself". Koskela (1992) further states that 'even if there is a lack of data on internal waste in design, it can be inferred that a substantial share of design time is consumed by re-doing or waiting for information and instructions'. It is much easier and cheaper to prevent or correct an error during the design process than in the later stages of a project. Design errors can be reduced if consultants develop and practice the facets of quality management (Koskela and Huovila, 1997). As rework is reduced, performance, productivity and quality will improve, which will reduce costs and increase profit (Phillips *et al.*, 1983).

Quality management sub-system influence diagram

The quality management sub-system relates to operational and management processes of the project system (Figure 1). The important considerations here are QA, partnering and strategic alliances, incentives and rewards and process improvement. Figure 3 provides a summary of those factors found from the interviews and literature that influence rework in the quality management system.

In project A, the relationship between the consultants and contractor was considered by both parties to be unpleasant. The consultants had not worked with the contractor before and it was axiomatic that there was a great deal of tension between parties and a reluctance to work together. The contractor perceived that the lack of attention to quality by the designers inhibited the development of teamwork and joint problem solving. As the project progressed and design errors became increasingly prevalent, the more time the contractor spent trying to solve the problems on site.

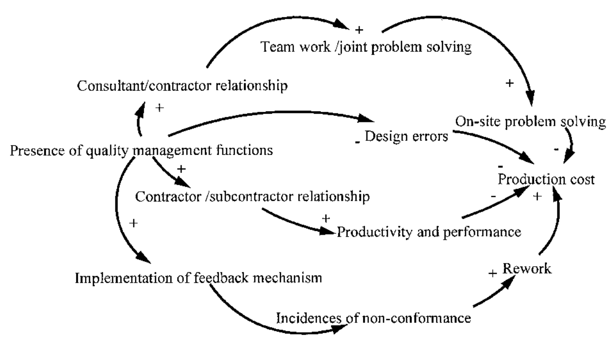

Figure 3. Major influencing factors of rework in the quality management sub-system

It was clear to the authors from conversations undertaken with the architect and engineer that they did understand the information needs of the contractor. When the architect and engineers visited site and gave a verbal instruction the contractor would not perform the activity until the instruction was confirmed in writing, primarily because on several occasions prior to this event the architects changed their minds when they got back to their office and subsequently refused to confirm the verbal instruction, despite the work being undertaken. The costs of correcting failures can be considerable in terms of cost and time. For example, Hammarlund and Josephson (1991) found the cost of correcting failures may be as high as 6% of production costs and the time taken to rectify these errors may be as high as 11% of the total working hours allocated for the project. Without doubt, time and effort can be saved if trust and commitment are in place. In both projects the contractor had a very good working relationship with the subcontractors. Many had worked with the contractor on previous projects. The relationships with the subcontractors had been developed over numerous years. They were founded on trust, commitment, and cooperation. The contractor effectively communicated tasks to the subcontractors. When a rework event occurred and was difficult to solve, then the contractor and subcontractor attempted jointly to solve the problem. These identified attributes were considered to be the fundamental foundations for a relationship between the contractor and subcontractors. Once these are firmly in place productivity and performance may improve (Kwok and Hampson, 1997).

Many rework incidents were not made formal, especially those less than $500. For example, in project B the schedule of finishes indicated that the doors in the storeroom were to be red, yet they were supposed to be blue. The architect had specified the wrong colour. The subcontractor rectified the problem at no additional cost to the client.

Non-conformance costs have been found to be between 10% and 20% of the total project cost (Cnuddle, 1991). There were no non-conformances issued on either project (Table 1). The foreman verbally informed the subcontractor and suppliers of the poor quality and it was rectified without delay. The foreman stated that it was too time-consuming to prepare formal non-conformances. This was seen, however, to be in conflict with the company's process improvement policy, as there was no feedback mechanism to ascertain the sources and types of non-conformance. It was perceived by the authors that the absence of a formal approach to process improvement in place meant that information was lost and activities that need to be improved in order to reduce or eliminate rework could not be identified.

Projects that have a formal quality management system in place have been found to record lower levels of rework (CIDA, 1995). The average cost of rework as a percentage of contract value for projects with a quality system has been found to be 0.72% (CIDA, 1995). However, those projects without a quality system in place have been found to have an average cost of rework of 6.5%. In fact, when TQM is applied holistically rework is significantly reduced and can be virtually non-existent if incentive schemes are introduced (Burati *et al.*, 1992). Without a quality culture in an organization it may become difficult to adopt effective partnering and strategic alliances. By implementing a partnering philosophy rework can be reduced significantly (CIDA, 1993).

Human resources sub-system influence diagram

The human resource sub-system relates to the support provided by the employees' organizations so that they can perform their jobs effectively and productively. The important considerations here are training, motivation and skill level. Figure 4 provides a summary of those factors found from the interviews and literature that influence rework in the human resource subsystem. Findings from the interviews with the quantity surveyor and contractor in both projects revealed that they considered that a large portion of the rework costs experienced in the projects were attributable to the poor skill levels of the clients' project manager, the design team and subcontractors. The main causes of rework identified as a result of poor skills were defective workmanship, disturbances in personnel planning, delays, alterations, failures in setting-out and coordination failures. The cause for 50% of the rework costs in project A arose because of the poor motivation levels of the architects and engineers. In project B the cause for 40% of the rework costs was the poor motivation levels of the site workforce.

In both projects none of the consultants involved had a quality management programme in place. Training and skill development were not issues that the consultants addressed, primarily because of the associated costs involved. The authors through their conversations with the architect and design engineers came to the conclusion that the lack of training and skill development with information technology applications such as CAD adversely affected the motivation levels amongst those employees working on the projects. The architectural practice in project B used recent graduates to perform senior tasks because their fee was considered to be tight. As a result errors and omissions emanated, as the architects did not have the skill and experience to perform their particular task. The contractor, mechanical, hydraulic, and electrical subcontractors all suggested that poor workmanship, as a result of poor training, was a major root cause of rework.

Causal loop diagram

The utility of the influence diagrams developed above is in their ability to explain the likely scenarios of rework if changes or omissions occur in some part of the project system. For example, if the function of training were strengthened would the incidence of rework be reduced? An overall causal loop diagram incorporating Figures 2–4 is needed to trace the overall impact of training. Figure 5 illustrates an overall causal loop model of the influencing factors of rework in a project system, and can be used to trace the effects or influences of rework factors on the project systems outputs, such as project cost and duration. The effects of any change in the degree of quality management implemented will have an effect on project costs. For example, if teamwork and on-site problem solving are implemented, then rework costs can be reduced. Similarly, changes in training and skill development practices can be traced to illustrate their effect on project duration and rework costs. However, Figure 5 does not illustrate the influences the major output factors have on the causal variables of the project system. For example, how would an increase in project costs influence quality or training and skill development programmes and what are the consequences?

Figure 6 indicates the major factors that influence project costs. It is assumed that if project costs increase, profit margins will be reduced and the expenditure on training and skill development programmes will be reduced to compensate for the cost increases. However, a reduction in the budget for training and skill development ultimately could increase project duration and rework costs, thus leading to a vicious circle, which can be identified by positive feedback loop 'A' in Figure 6. Similarly, another effect of increasing project costs can be identified by feedback loop 'B'. This information feedback loop suggests that as project costs increase a strain may be placed on organizations' quality programmes, and therefore divert their attention from being quality focused. The information link from project costs to the strain on quality management programmes has created another major feedback loop 'C', which indicates that a lack of a quality focus can affect the rate at which design errors can be detected and the number of changes experienced. In the same way, an information link from project costs to training and skill development has created an additional major positive feedback loop 'D'. This feedback loop indicates that skill level will influence the quality of workmanship, which in turn can have a positive or negative influence on rework and project costs.

As mentioned earlier, the overall causal loop diagrams presented in this paper were constructed using qualitative data and findings from previous research. The

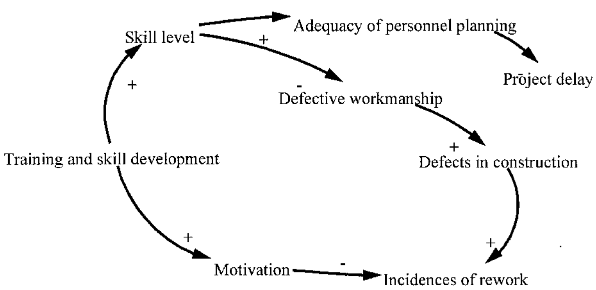

Figure 4. Major influences of rework in the human resource sub-system

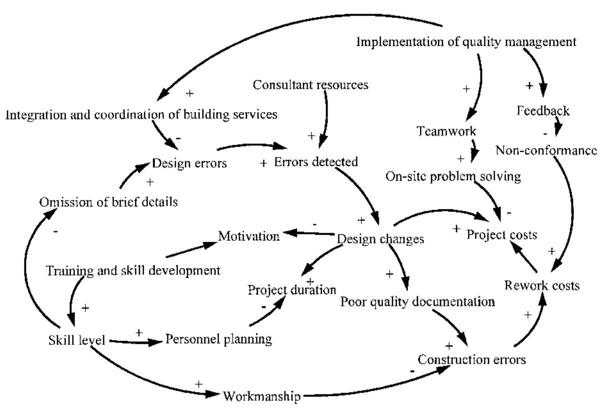

Figure 5. An overall causal loop model of rework in a project system

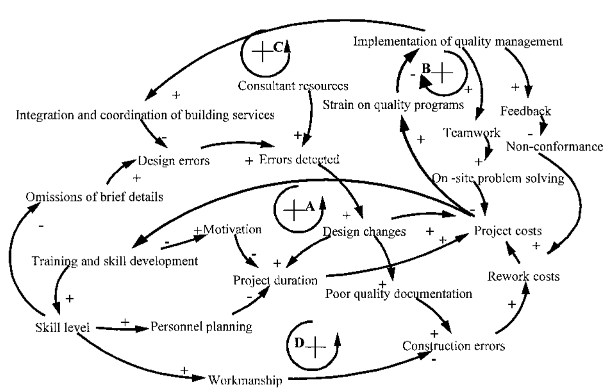

Figure 6. A conceptual model of rework based on causal modelling concepts

details in the diagrams may vary from project to project, but the fundamental theme(s) of the diagrams should be similar. By creating a detailed model and identifying the main feedback loops, the major rework influences in a project system should be readily identifiable. Essentially, the feedback loops assist in pinpointing the primary areas in the system that need to be addressed so that rework can be reduced or eliminated.

Conclusion

Total quality management principles have not been implemented effectively in the construction industry. As a result, rework has become an inevitable feature of the construction process. The incidence of rework increases the likelihood of project time and cost overruns, and ultimately leads to customer dissatisfaction. The causes and effects of rework are readily identifiable from previous research. This paper has suggested that to reduce or eliminate the incidence of rework we need to understand the causal structure of rework influences.

The concept of system dynamics modelling has been used to examine the effect that one variable has on another. Systems dynamics principles have been used to map and identify the major variables that influence the incidence of rework. This approach has assumed a holistic view of the project organization by focusing on the behavioural trends and their relationship with management strategies. General assumptions about the behaviour of rework in a project system have been determined by using influence diagrams. These diagrams were integrated to develop a conceptual causal loop model to determine the overall causal structure of rework. The model can be used to identify the main feedback loops, which can be used to determine the major variables that influence rework. The qualitative model developed in this paper has provided an insight into the causal nature of rework in a project system. This model can provide researchers and practitioners in construction with a richer understanding of the interdependence between a project's subsystems and the management challenges associated with identifying effective rework prevention strategies. The model also encourages a paradigm shift in how we view a project system: away from the traditional mechanistic view to a holistic viewpoint. If rework is to be reduced or eliminated we must focus on the whole system rather than on individual parts.

In our future research, improvements will be made to better model the interrelationships of activities and managerial interventions (e.g. resource re-allocation to expedite activities) made by project managers to rectify problems. One type of interrelationship identified between activities is the feedback loop: for example, if activity X affects activity Y, activity Y may also directly or indirectly affect activity X (Williams *et al.*, 1995). Our future work will take these into account in order to identify the most effective rework prevention strategies.

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