DECOREM: A Design and Construction Rework Minimisation Model

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ABSTRACT: *Rework that is often experienced in construction projects is primarily caused by errors made during the design process. Factors that contribute to design errors are identified and used to design and develop a systems dynamics model, which is used to simulate a number of practical scenarios that can be used to reduce design errors and rework. The **DE**sign and **CO**nstruction **RE**work **M**inimisation (DECOREM) management model presented in this paper can enable design and project managers to better understand the process of design documentation and how design errors occur in construction projects.*

Keywords: System dynamics, design management, time boxing, design errors, rework.

INTRODUCTION

Rework is the unnecessary effort of re-doing a process or activity that was incorrectly implemented the first time. It is an endemic feature of the construction procurement process and is a primary factor that contributes to time and cost overruns in projects. The direct costs of rework in construction projects are considerable and have been found to range between 10-15% of contract value (CIDA, 1994). Such costs could be even higher as they do not represent the latent and indirect costs and disruption caused by schedule delays, litigation costs and other intangible aspects of poor quality. The primary sources of rework in construction are naturally, the documentation on which the construction activity is based. These largely consist of design changes, errors and omissions (Love *et al*., 1999). Thus, in order to understand the origins and causal nature of rework it necessary to model the design process in order to determine why and how rework originates so that it can be prevented through integrating design management with project management. This paper builds upon the earlier work of the authors reported in Love *et al*. (1999), which used case studies to determine the causal nature of rework in construction projects. Using the findings from the authors previously reported research, this paper uses the methodology of system dynamics to model those factors that were found to cause design error induced rework. A **DE**sign and **CO**nstruction **RE**work **M**inimisation (DECOREM) model is developed and used to simulate a number of practical scenarios that can be used to reduce design errors and rework. DECOREM aims to provide an insight and better understanding of the factors that influence the occurrence of design errors in contract documentation. It is suggested that a reduction in design errors and rework can improve the profitability and competitiveness of a design firm and the performance of construction projects.

MODELLING APPROACH FOR DECOREM

This paper focuses on modelling and analysing those factors that influence the occurrence of rework during the design process. This paper uses the generic term 'designer' to mean both architects and engineering consultants and focuses on the practices of the design firm. The methodology used to develop the model presented in this paper can be found in (Love *et al*., 1999). The developed model was presented to a number of practicing architects and engineers to test its validity. The factors that were used in the model were considered representative of practice and therefore adequate for the purposes of modelling. Estimates for the model's parameters, that is, project duration, contract value, were derived from the case studies presented in Love *et al*. (1999). In addition, practitioners provided estimates for designer salaries, and design fees, which ranged from 5-8% of contract value. Although, it was stressed that project type and method of procurement significantly influenced the fee charged (Rawlinsons, 1998:p.760). The developed model consists of the following interrelated sub-systems: *process of inducting/recruiting design personnel; process of designing tasks; error proneness during design; and re-designing design tasks.*

Process of inducting/recruiting design staff

Typically, the composition of personnel within a design firm will vary with the firm's workload. Essentially, there are three different types of designer: *experienced*; *newly recruited*; *and inducted* (ie, an experienced designer working on other projects within the design firm but may be seconded to a new project). It is noteworthy, that the productivity and accuracy of tasks undertaken during the design process will vary from one group to other (Abdel-Hamid and Madnick, 1991). Thus, when determining staffing levels within a design office the model assumes that the partner(s)/office manager takes a rational approach to selecting and recruiting new staff. Thus, based on their design schedule, the partner(s)/office manager will determine the number of designers needed for a project and then compare those who are available. The difference between the number of designers needed and those available is referred to as the shortfall (-) or surplus (+). If there is a shortfall for a new/current project, the partner/office manager may decide to either recruit additional staff or internally induct staff. Whether a designer is recruited or inducted they have to become familiar with the project's characteristics, requirements and history. Consequently, a delay is experienced before they become 'experienced designers'. The time delay between new designers and experienced designers and between inducted designers and experienced designers is shown by double hash line in Figure 1.

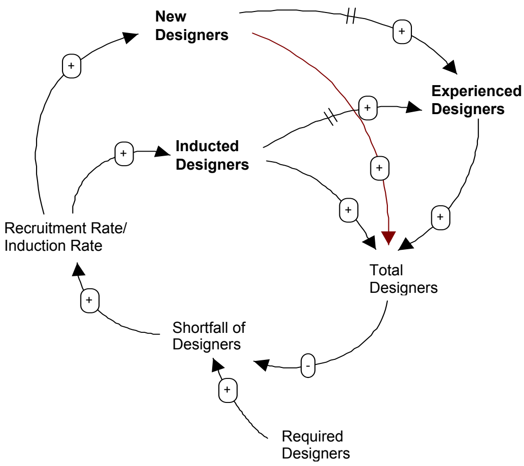

Figure 1. Process inducting/recruiting staff

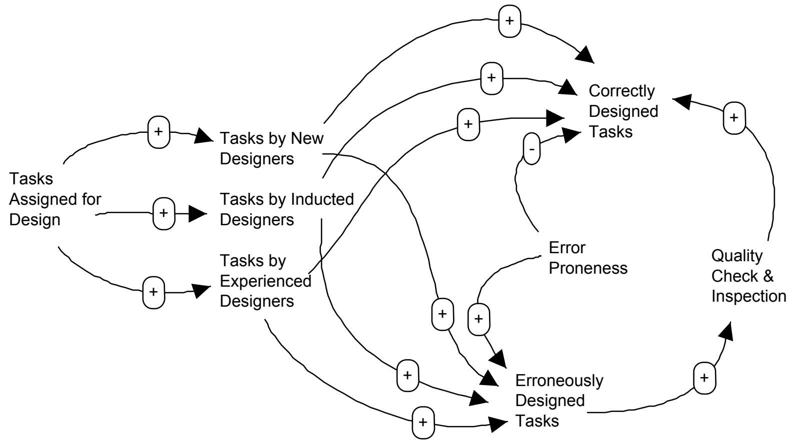

Figure 2. The process of designing tasks

The mechanisms explained above, and in subsequent influence diagrams, have been expanded further in developing the overall computer model of error in design. Powersim CONSTRUCTOR 2.5 package has been used in converting the influence diagrams into flow diagrams and writing the computer codes. A description of all the major equations used to develop the model is considered to be beyond the scope of this paper. However, a full list of the equations used to develop the model is available upon request to the authors.

Process of designing tasks

In Figure 2 design tasks are assigned among the three different groups of designers. Figure 2 suggests that are two possible design outcomes– the design is completed correctly or the design is done erroneously. Depending on the error proneness of the designer, (that is the likelihood of the designer to make mistakes) the number of correctly designed and erroneously designed tasks can be determined, although this will vary between each designer type

(Abel-Hamid, 1989). The model identifies the number of tasks designed correctly and incorrectly by each type of designers. It assumes that the design firm undertakes quality checks/design reviews to identify those tasks erroneous so the contract documentation can be corrected before contractors price and tender for the project.

Error proneness during design

The factors that contribute to error proneness are identified in Figure 3. The authors have assumed that the identified designer types will each be subject to different degrees of error proneness (Abdel-Hamid and Madnick, 1991). Therefore, a nominal value for committing error is determined in the model, which can be seen in Table 1. This error value is deemed rise as schedule pressure increases, when design fees are low, and when the degree of parallelism between tasks carried out by different designers increases. In other words, as tasks are performed concurrently the number of interactions increases and the likelihood for errors to occurring also increases (Williams *et al.*, 1995). Low salaries can act as de-motivators, which in turn may also contribute to the incidence of errors (Abdel-Hamid, 1989). Similarly, when a firm submits a low design fee for a project, it may 'time box' tasks. In other words, only a fixed time is allocated to complete each task, irrespective of whether the documentation is complete or not. In turn this can also cause errors being made by other parties who rely on the designers' curtailed information.

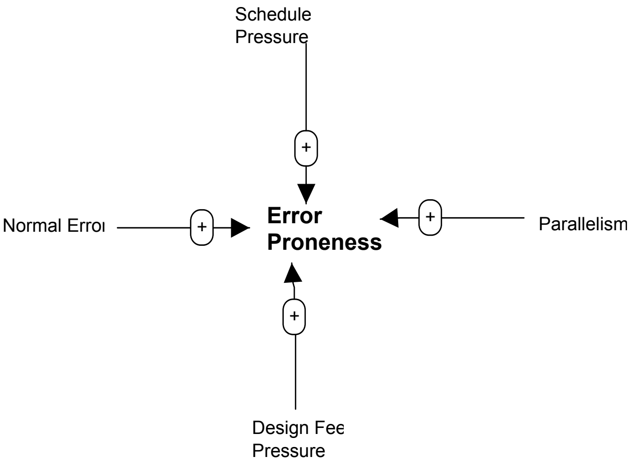

Figure 3. Error proneness during design

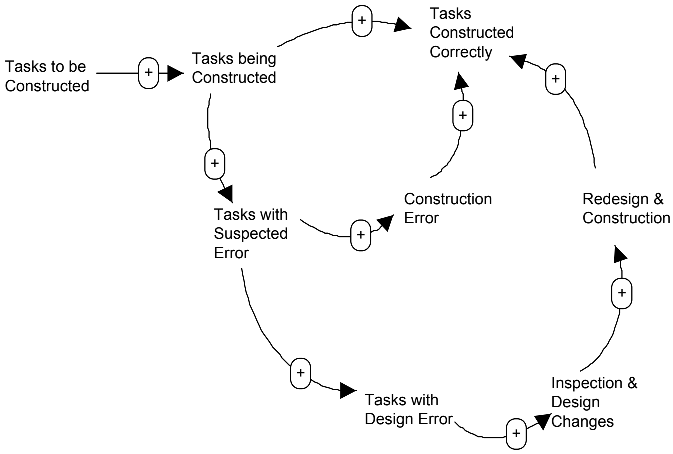

Figure 4. Process of re-designing design tasks

Re-designing design tasks

Once the design and contract documentation is complete it is passed on to the contractor to price. At this point, the authors assume the contract has been let to a selected main contractor and construction has commenced on site. As construction on-site progresses errors are inevitably found in the contract documentation. Similarly, some elements are constructed incorrectly (see Figure 4). If the suspected error is proved to be the responsibility of the contractor or the subcontractors, then the error may be rectified (rework) with no added cost to the client of the project. On the other hand, if the architect or engineer caused the error then they will be responsible for solving the problem. Unless it is a simple problem a particular item or selection of work may need to be re-designed. The design firm may have to recall the designer(s) responsible for that part of the design and documentation process to undertake the necessary rework. If the original designer(s) have left the firm the process of recruiting/recruiting may well commence again as shown in Figure 1. However, for the purpose of this paper, the authors have assumed that the designer(s) can be easily recalled to the project. It is assumed that as construction progresses on-site, errors in the contract documentation will be identified by the contractor/subcontractors. As they are identified the process of confirmation and redesigning of tasks will commence as shown in Figure 4.

MODEL SIMULATION AND ANALYSIS

In conjunction with industry practitioners, the authors have determined the parameters used to model the influence of design errors. Table 1 identifies some of the data and assumptions made in the model for the purposed of generating a series of possible scenarios for a given project.

Table 1. Data and assumptions made in the model

Characteristics	Assumption
Designer's average salary	$1000 per week.
Scheduled design completion time	40 weeks
Project cost	$10 960 000
Design Fees (in percentage of project cost)	5%
Estimated effort in the design stage	548 person-weeks
Construction Start time	40th week.
Available designers (initially)	10 persons.
Construction Time	43 weeks
Design Error Proneness	
- by expert designers	10 percent of tasks
- by designers inducted from other projects	20 percent of tasks
- by newly recruited designers	25 percent of task

The process of model validation is multifaceted. The model has been examined for structural validation inasmuch as the major factors identified in Love *et al.* (1999) have been used and the values used in the model validated by industry practitioners. The model was tested for behaviour prediction so as to assist practitioners with particular scenarios they may be faced with. Figure 5 depicts the simulated behaviour for the time allocated for the design and documentation process in comparison to the design schedule.

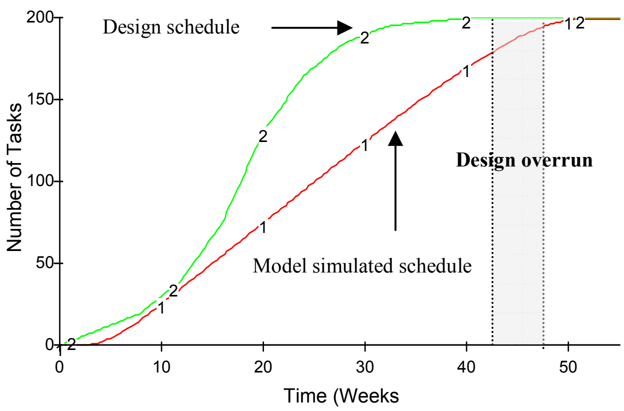

Figure 5. Design tasks *v* the actual schedule.

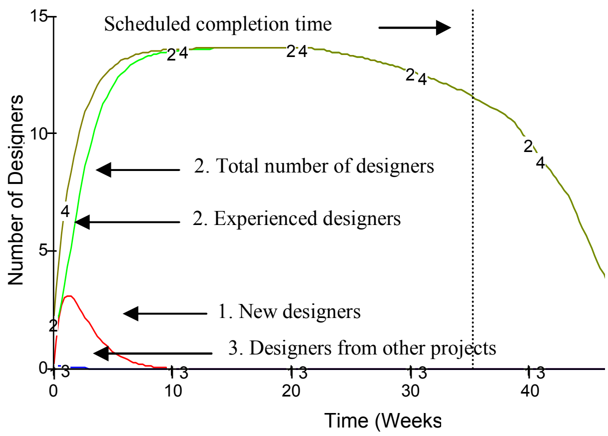

Figure 6. Design staff required for documentation

For the example used in this paper, the model shows a simulated design completion time of 45 weeks (for the completion of 95% activities) compared to a scheduled design completion time of 40 weeks (Table 1). Figure 5 shows the behaviour of actual design activities completion against the forecasted schedule. The actual progress always remained below the scheduled design activities. This is explained by the fact that the design firm takes time to recruit and train design personnel. However, design firms often neglect this factor when planning their design schedule for projects (Ogunlana *et al.*, 1998). Figure 6 exhibits the allocation of design staff during the documentation process. Figure 6 shows that more design staff is allocated to design and documentation process during the early stages of the project. Similarly, the number of design staff decreases as tasks are completed. The actual effort (measured in person-week) in the documentation process is marginally above the estimated effort, that is, 556 person-week against the target of 548 person-weeks. At least 43 activities in total have been modelled are designed erroneously in this example. It is assumed that of these, 28 errors are design based, which are detected on-site and therefore have to be redesigned. The period for amending the errors (redesigning of activities) takes 14 person-weeks effort (refer to Table 2). With a 40-week period for documentation and 43-week construction period, the simulation indicates that at the 105th week only 95% of activities will be completed. 'Time boxing' may occur at, or even before this point is reached. The number of designers that need to be recalled during construction for correcting errors identified in the contract documentation was simulated and calculated. Though a small fraction of a single designer's time is utilised, over the whole project time the redesign time was equivalent to a designer working full time on correcting errors for 14 weeks.

TESTING OF ALTERNATIVE SCENARIOS

To further understand the dynamics of error induced rework in a project system the following scenarios were tested:

1. Continue with the present situation.
2. *Drastically reduced design time* - Due to external pressure, a project manager could accelerate the design and documentation process of the project. For example, the design schedule could be compressed from 40 weeks to 25 weeks. No other change is affected: Salary is $1000 per person per week, available design personnel from other projects are 10.
3. *Drastically reduced design time with engagement of experienced design personnel* - It is assumed that paying an additional salary (in terms of overtime payments) will be attractive to experienced design staff. The salary is increased by 50% to $1500 per person per week. The scheduled design completion time is kept at 6 weeks.
4. *Recruiting a high proportion of design personnel from external sources* - In the event of awarding a new contract design firms in normal circumstances use their existing personnel, As this may be less disruptive. However, if there is a shortage of internal design staff the design firm may have to externally recruit design staff. Reducing the number of available design staff from 10 to 5 can test this scenario. Salary is set at $1000 per person per week and the scheduled design completion time is 6 weeks.
5. *A combined policy incorporating a design fee reduction, short design delivery period and reliance on external supply of design personnel* - Design fee (% of project cost) is reduced from 5% to 4%. Design completion period is 25 weeks and the available design personnel from internal sources are only 5.

Table 2. Summary of scenario results

Scenario	Number of Tasks Designed Erroneously	95% Design Completion (weeks)	95% Project Completion (weeks)	Number of Activities Redesigned	Effort Spent on Re-design (person-weeks)
Scenario 1	43	45	105	28	14
Scenario 2	82	30	98	53	26
Scenario 3	48	29	98	35	17
Scenario 4	84	30	98	54	27
Scenario 5	59	30	98	41	21

In Scenario 2 the design schedule is reduced from 40 weeks to 25 weeks. Consequently, this requires designers to raise their productivity without an increase in salary, which may have de-motivating consequence contributing to more errors being made. In this scenario, the effort to design has risen by 5% and the number of erroneously designed activities increased by almost 100%. To complete the design activities in a shorter period, the design firm may have to recruit a large number of inexperienced personnel, but due to their high error proneness errors may increase. As a result, the number of redesigned activities and the effort required would increase by 90% and 85%, respectively, when compared to scenario 1. Scenario 3 appears to be a reasonable approach as a reduction in the design and documentation period would require the design firm to pay higher salaries for better qualified personnel. The implications of implementing this scenario are that the design and documentation period would be completed within 390 person-weeks and the required effort would be 30% less than that in Scenario 1. The number of errors in both the initial design and redesign stages is similar to that found in Scenario 1 (Table 2). The behaviour observed in Scenario 4 is very similar to that in Scenario 2. In Scenario 4, due the lack of available in-house design staff, the design firm could be compelled to recruit inexperienced design staff from external sources. In effect this may increase the number of committed errors, and consequently more effort may be required during the design and documentation process. Moreover, as errors occur increased effort may be needed to re-do erroneous activities. Scenario 5 may be considered to be the most inappropriate policy. A reduction in the design fee from 5% to 4% as well as a reduced design and documentation period may be force the design firm to produce contract documentation with minimum effort and 'time boxing', which can lead to higher levels of error being experienced.

CONCLUSION

The DECOREM model has enabled the authors to unravel a series of complex problems into more manageable interrelated components. Whilst this version of reality may not capture the mass of complexity, the authors suggest the model presented in this paper can enable design and project managers to better understand the process of design documentation and how design errors occur in construction projects. To reduce the likelihood of design errors occurring in a project, practitioners need to have a mechanism to test various alternative scenarios so that the design and documentation process can be managed more effectively. The analysis of the interrelated factors in design scenarios tested can assist industry professionals in making rational decisions as to which factors need the most attention in reducing their rework. The scenario analysis demonstrated that short term measures such as recruiting from external sources to cope with sudden rises in demand for design personnel, submitting low design fees to win a contract and subsequently paying low salaries to designers are considered ineffective management practices in the long run. Noteworthy, each of these options may contribute to an increase design errors and therefore rework, especially if inexperienced staff is subject to time boxing. In some cases, rework will demand a significant amount of additional time to rectifying design errors that are identified during construction. It must be acknowledged that only those responsible for managing a design firm can make the decision as to which design management strategy they adopt to help them with their decision-making. Without an understanding how errors affect a firms overall performance, design fees will be perceived to be low as additional resources undertake rework. Clearly, a reduction in design errors will project a better professional image of the firm, lead to more effective design management, but more fundamentally it will improve the profitability and competitiveness of a design firm.

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