QUANTIFYING THE TIME AND COST ASSOCIATED WITH THE REQUEST FOR INFORMATION (RFI) PROCESS IN CONSTRUCTION

S. Mohamed, P.A. Tilley and S.N. Tucker[1]

ABSTRACT: Ideally, project documentation should be complete and there would be no need for subcontractors to seek further information from that which has already been provided. In practice, this is rarely the case. The use of "Request For Information" (RFI) as a formalised process, by which information is gathered or clarified is very common throughout the Australian construction industry. This paper focuses on the use of simulation-based modelling to quantify the time and cost associated with this process as currently communicated between construction organisations. Information gathered from construction projects plus expert advice sought from industry professionals is incorporated as model input. The model shows that the mean cycle time for a typical RFI can be as high as 17 person-hours with most of that time being spent on gathering and cross-referencing information. The simulation model was then modified to explore the potential of implementing Electronic Data Management Technologies as a tool to significantly reduce the time and cost associated with the traditional paper-based RFI process.

Keywords: Request for information, project documentation, information management, electronic data management, simulation modelling.

INTRODUCTION

The construction industry is information intensive and effective information management is of concern to all sectors of the industry. Poor information management is believed to be responsible for undesirable features of construction projects such as delays and rework (Love et al., 1996). Driven by the growing need to better manage and exchange project information, coupled with the remarkable advancement in information technology (IT) tools, a large number of recent studies have addressed concepts and applications such as:

- Mapping the data flow within a construction organisation (Fisher and Yin, 1992);
- Managing design information (Bennett et al., 1994);
- Modelling and standardising the handling of product information (Bjork, 1994; Eastman et al., 1994; Augenbore, 1994);
- Exchanging messages via electronic means (Vries and Somers, 1995); and
- Integrating project information (Brandon and Betts, 1995; Kim and Ahn, 1996).

Little attention, however, has been paid to quantifying the time and cost associated with current methods and the potential direct savings, if these methods are improved. It is expected that indirect savings could also be much higher as effective communication of project information contributes significantly to minimising workflow disruption.

Project information is usually supplied to contractors and subcontractors in the form of engineering drawings and written specifications. Ideally, this would be complete and sufficient for the purpose of proceeding with construction. When subcontractors are supplied with project documentation that is incomplete, conflicting or erroneous, they resort to the 'Request for Information' (RFI) process. This is a formalised process by which additional information can be clarified or obtained.

The number of RFIs issued throughout the project lifetime is dependent on many factors including the project size, duration, organisation, contractual arrangement, and most importantly the quality of design documentation. Although the primary function of the RFIs is to formally request additional information, or clarifications to existing information

[1]Dr Sherif Mohamed, Griffith University, PMB 50 GCMC, QLD 9726, Australia, S.Mohamed@mailbox.gu.edu.au
Mr Paul Tilley, CSIRO–Building, Construction & Engineering, PO Box 12072, Brisbane QLD 4001, Australia, Paul.Tilley@dbce.csiro.au
Dr Selwyn Tucker, CSIRO–Building, Construction & Engineering, PO Box 56, Highett VIC 3190, Australia, Selwyn.Tucker@dbce.csiro.au

(Tilley, 1997), contractors and subcontractors tend to use the ease of RFIs tracking for other purposes including:

- Approvals; where drawings, documents, material samples or technical information submitted to the design team/client for approval; and
- Confirmations; where requests are made for confirmation of both verbal and written information, provided in a manner that is not contractually binding on the contractor.

RFIs differ in nature, number of issues raised, number of people involved, and urgency. Case study projects have shown that Clarifications RFIs used for clarification purposes are the most numerous as shown in *Figs 1 and 2;* the distribution and cumulative number of RFIs issued for a construction project over a period of 24 months, respectively (after Tilley, 1997). Therefore, this paper focuses only on the process of the RFI clarification type as communicated between quality-assured construction organisations.

The main objective of the research presented in this paper was to build a dynamic simulation model of such a process from the perspective of current message exchange practice, then to use the model to quantify the time and cost associated with the process. A second objective was to simulate the impact of Electronic Data Management Technologies (EDMT), if implemented, on the process performance through identifying potential time and cost savings.

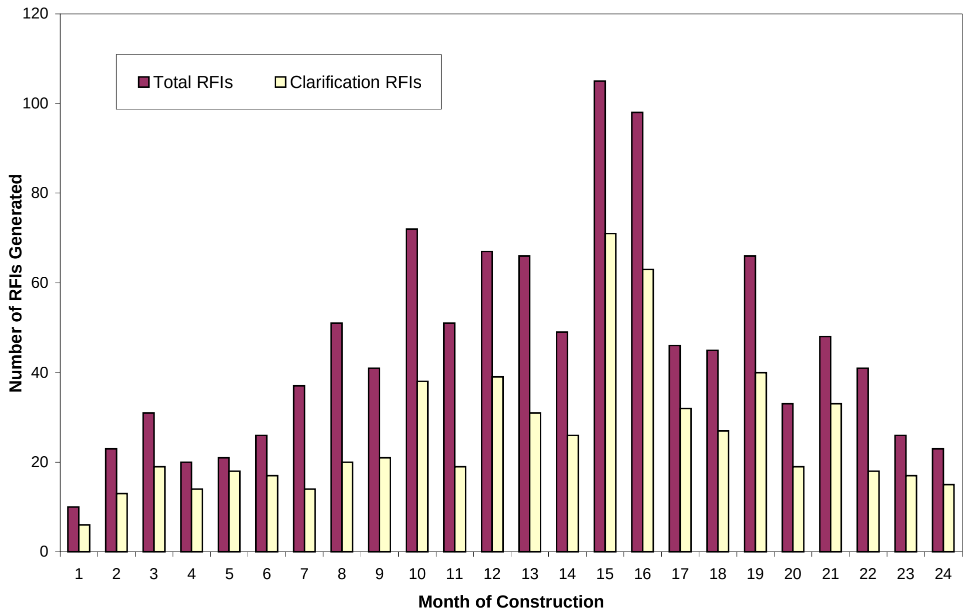

Figure 1: Number of RFIs generated over a period of 24 months

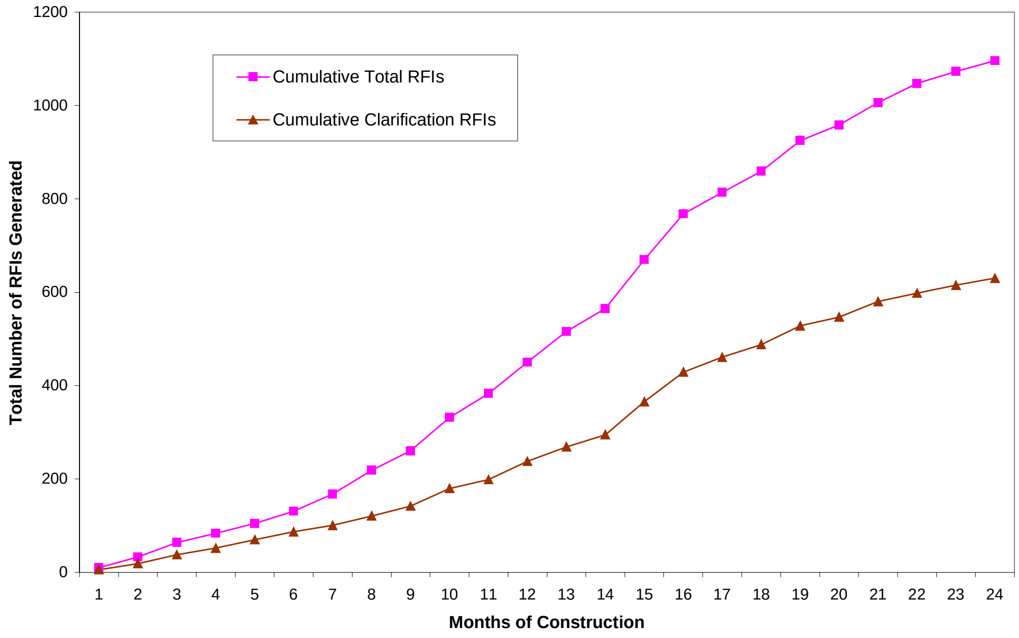

Figure 2: Cumulative number of RFIs generated over a period of 24 months

THE RFI PROCESS

A process is composed of inter-related tasks where a task may be defined as the basic element of a workflow process which requires time to perform (Halpin and Riggs, 1992). The following scenario, shown diagrammatically in *Fig 3*, depicts the major tasks, sequencing and individual professionals engaged in each task of the RFI process:

When a subcontractor needs more information to resolve a problem or perform a task, he, in collaboration with the general foreman, fills out an RFI form. The general foreman then discusses the RFI form with the site clerk who, in turn, proceeds to process the RFI. The site clerk prepares multiple copies of the RFI and sends (usually by fax) the original to the person who is thought to be most capable of responding to the query raised (say the architect). A copy of the RFI with the appropriate attachments is sent to the main office of the contracting organisation. The site clerk date stamps another copy of the RFI and files it for circulation (as per quality assurance procedure for document control).

Once the architect receives the RFI, he/she searches office files for relevant documents and/or drawings which are applicable to the query. The architect then responds to the RFI by sending his/her instructions to the site clerk. Following the receipt of site instructions, the site clerk sends a copy of the instructions to the project manager (usually by fax) and issues them as per distribution to the subcontractor via document transmittal. A copy of the document transmittal is also sent to the main office.

The site clerk organises a meeting with the project manager, general foreman and contract administrator to discuss site instructions. The purpose of this meeting is to determine if these instructions constitute a variation of the contract. If this is so, the contract administrator issues a letter to the superintendent requesting a verification order which will then be sent to the subcontractor. Otherwise, the instructions are sent to the subcontractor and documented in the RFI register.

From the above scenario, it can be seen that the RFI process can be disruptive and time-consuming with a number of individuals; the subcontractor, general foreman, site clerk, architect/engineer, project manager, superintendent and contract administrator involved at different stages of the process. Needless to say, more time could be wasted in the process of contacting those individuals, especially if face-to-face meetings are required. Also, the risk of not responding adequately and timely within the requested time frame might have serious consequences on the workflow.

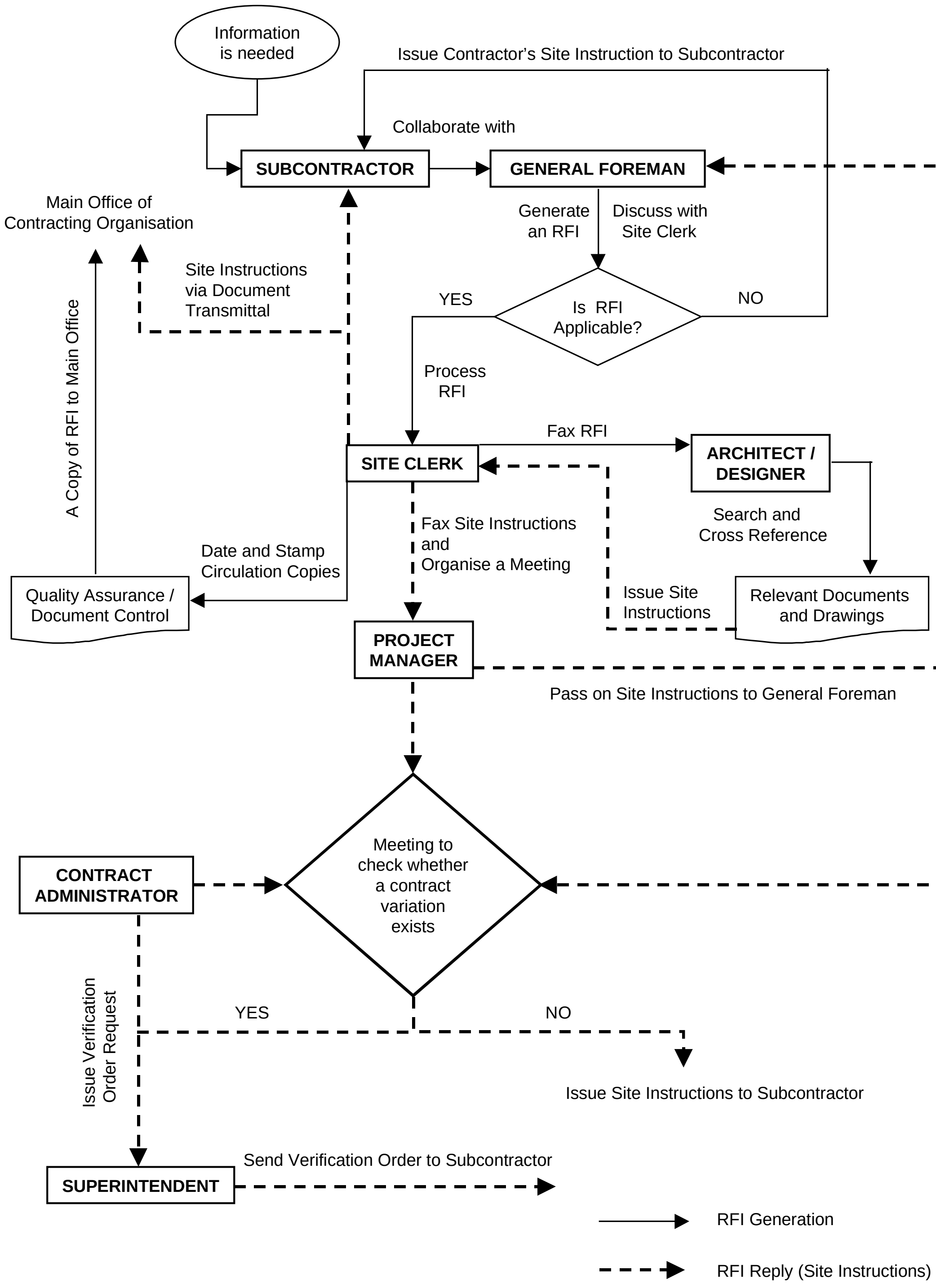

Figure 3: The RFI process as adopted by quality-assured organisations

Fig 3 demonstrates that the RFI process consists of a number of tasks with clear precedence. However, task duration (time elapsed from start to finish of a task) is difficult to determine as it varies dramatically from one RFI to another. To complicate the process further, it is not uncommon for a number of RFIs to be re-sent, as the reply (sent to the subcontractor) contains insufficient information. It is therefore difficult, without the use of an appropriate modelling tool, to quantify the time spent by all professionals engaged in the RFI process.

It should be emphasised at this stage that the RFI process, as described above, is not applicable to all construction project types. Clients, their representatives and project managers may choose and agree upon a different information clarification arrangement. However, based on monitoring information flow on a number of recently completed construction projects, the authors believe that the above scenario reflects how RFIs are actually issued and processed by the majority of quality-assured Australian contracting organisations.

JUSTIFICATION OF USING SIMULATION MODELLING

There are many ways in which a managerial information system, or aspects of it, can be represented (Fisher and Yin, 1992). Data Flow Diagram (DFD) modelling is a well-known technique for graphically describing the data processes and the flows of data between them. This technique has been successfully used in design modelling (Gharib, 1991). Entity Relationship (ER) modelling is another technique which has the ability to add attributes describing the flow process. It is primarily used for the development of relational databases-based applications (Rob et al, 1991). Both DFD and ER modelling are principally static in nature. As a result, their modelling capabilities do little to represent the dynamic environment characterising the RFI process.

The RFI process is intrinsically dynamic; it has multiple time delays in carrying out individual tasks. Time spent on each task is dependent on available human resources, task urgency, number of items raised per RFI, means of transfer, just to name a few. In view of these factors, a large variance in task duration would be expected. Therefore, a planning tool such the Critical Path Method (CPM) would not be suitable due to the deterministic and static nature of its representation. CPM simply adds time for nodes on a specified path with no explicit control on the entity flow, storage, waiting time, stochastic (variable) duration and other modelling assumptions. The shortcomings of CPM are numerous and are well-documented (Pritsker et al, 1989).

Considering the many factors involved in the time-based RFI process, a quantitative modelling technique was required to capture such factors, associated variables, and uncertainties. Simulation modelling was developed to deal with exactly such dynamics. The unique modelling flexibility inherent with computer simulation affords an opportunity to accurately model the generation and transmission of business transactions (Back and Bell, 1995a). Therefore, simulation was considered to be appropriate for providing an answer to the question “How much time does it take for an RFI to be processed?”. This would also lead to a reasonable estimate of the cost associated with each RFI issued.

Pritsker (1985) defines simulation as ‘the development of a mathematical-logical model of a system and the experimental manipulation of the model on a computer’. While the term simulation can have various meanings depending on its application, in construction management it refers to either statistical process simulation or graphical simulation (animation). The former is a generally accepted technique for modelling and analysing complex stochastic systems which change over time. It has been used in construction management applications for the past three decades. Emphasis in the majority of these applications has been on the impact of resource allocation on the production estimates for individual site operations. However, more creative applications in construction management have recently been reported (Baldwin et al., 1996; Tommelein; 1997; and Mohamed, 1998).

Several simulation languages have been developed for use in construction modelling. Oloufa (1993) gives a brief historical review of simulation languages. These languages were mainly developed with a focus on the analysis of materials handling and placement systems as they apply to construction sites.

A statistical process simulation model, in its simplest form, consists of entities representing work tasks and associated resources. Interaction between the model entities is achieved and controlled by means of links that specify the direction of resource flows and the precedence relationships between work tasks, i.e. the network logic. Model constraints are applied in the form of time and resource limits to simulate, as realistically as possible, the real system.

The chosen System Dynamics based software package ithink™ (High Performance Systems, 1994) simulates the behaviour of dynamic systems through the inter-linkages between a number of basic components classified as stocks, flows and converters. The package utilises generic elements that are not specific to information management. However, its modelling features not only make it significantly easier to create the model but, more importantly, capture the process uncertainties and the varied probability of events occurring. In addition, ithink™ provides guidelines for equation formulation. These guidelines can be thought of as rules for converting symbols and words into algebra (Morecroft, 1988).

MODEL DEVELOPMENT

The foremost step in modelling is to understand the process to be modelled. The process here is simply the handling and processing of an RFI once it has been issued by a subcontractor. The model is intended to represent current practice and as such it was based upon a recognised process, established by a quality-assured contracting organisation, for issuing, forwarding and receiving RFIs during the course of a project, as shown in *Fig 3*. The model represents a system whereby information is passed on from one person to the next until site instructions are sent to the subcontractor who raised the original RFI.

The model is composed of all those tasks that are related to the RFI process. The model contains a number of *Sub-Models* representing those persons involved; a *Sub-Model* for each one of the following: subcontractor, general foreman, site clerk, architect/engineer, project manager, and superintendent. Each *Sub-Model* contains a series of elements having their own set of varying times to simulate time delays associated with the process when this particular individual has possession of the RFI. Each task requires a specialist to spend a certain amount of time to accomplish it, and it was assumed that the specialist possesses the skill to carry out the task effectively.

A Detailed Sub-Model

In this section, a *Sub-Model* is described in detail to give insights on how the simulation model was developed. *Fig 4* uses ithink™ notation to graphically express the different elements associated with the Architect *Sub-Model* which can be described as follows:

Architect cross-references information, refers to the time the architect spends in searching office files for documents and/or drawings that directly cross-reference the issues raised on the RFI. Cross-referenced information may include previous problems that relate to a particular item.

Architect gathers information is the critical element within this *Sub-Model* as it represents the time that the architect spends in gathering the required information needed to directly answer the RFI. Prolonged periods of time can be spent in gathering the necessary data, and from the modelling viewpoint it represents the true time needed to successfully answer the RFI.

Architect fills out their standard RFI response form refers to the time it takes the architect to fill out the form which will be sent back to the issuer. This form contains the response to the RFI.

Architect organises transmittal refers to the time the architect spends collating the RFI response together with any attachments which accompany the response and preparing this bundle of information for transmission either by fax, mail, courier etc.

Architect files transmission documents refers to the minimal time spent here as it merely indicates the time spent in filing transmission documents. Transmission documents are common paperwork with respect to the exchange of information between construction participants. They are used to keep track of who received what and when, an element which is strongly affected with the implementation of EDMT into the RFI process.

Architect transmission refers to the time associated with the particular form of transmission employed by the person responding to the RFI. For the purposes of this model, it was assumed that the method of transmission is via a fax machine, as this proved to be the most common form of transmission.

The Architect's *Sub-Model* was chosen herein to illustrate the utilisation of built-in simulation function 'Monte Carlo' which ithink™ provides. This function allows a random series of 'zeros and ones' to be generated with the percentage of 'ones' being specified. A logical expression is then used to control the duration input, thus accounting for the large variance in duration which might be encountered during the 'gathering of information' task. Not all of the *Sub-Models* contain the 'Monte Carlo' function; only those that experience large variations in duration. For example, it is used in the Superintendent *Sub-Model* to incorporate an element which simulates the delays associated with RFIs which cause a variation to the original contract.

As mentioned earlier, each person involved with the RFI process has different processing delay elements attached to their *Sub-Models*. For example, the architect's *Sub-Model* has an element which represents the time he/she spends in searching for information which cross-references the problem raised, this time may be as high as several hours. In contrast, the general foreman, who may also search for information which cross references the problem raised on the RFI, will be inclined to spend much less time searching for information. Values attached to these time elements are determined from the survey results described in the following section. No limits were imposed on modelling resource requirements (professionals required performing the task). However, the number of RFIs processed by an individual was restricted to one at any point in time.

Input Data

As with any model, the quality of the input has a significant effect on output quality. To construct a meaningful simulation model, data was gathered from industry practitioners familiar with the RFI process. Input was derived on the basis of a survey designed to provide both quantitative and qualitative data to be directly incorporated into the model. The survey was targeted at all professionals involved in the process; architects, project managers, engineers, and contractors. It was assumed that the respondent has reasonably accurate ideas and intuition regarding the range of possible duration for individual tasks he/she performs. Questions were related to the following:

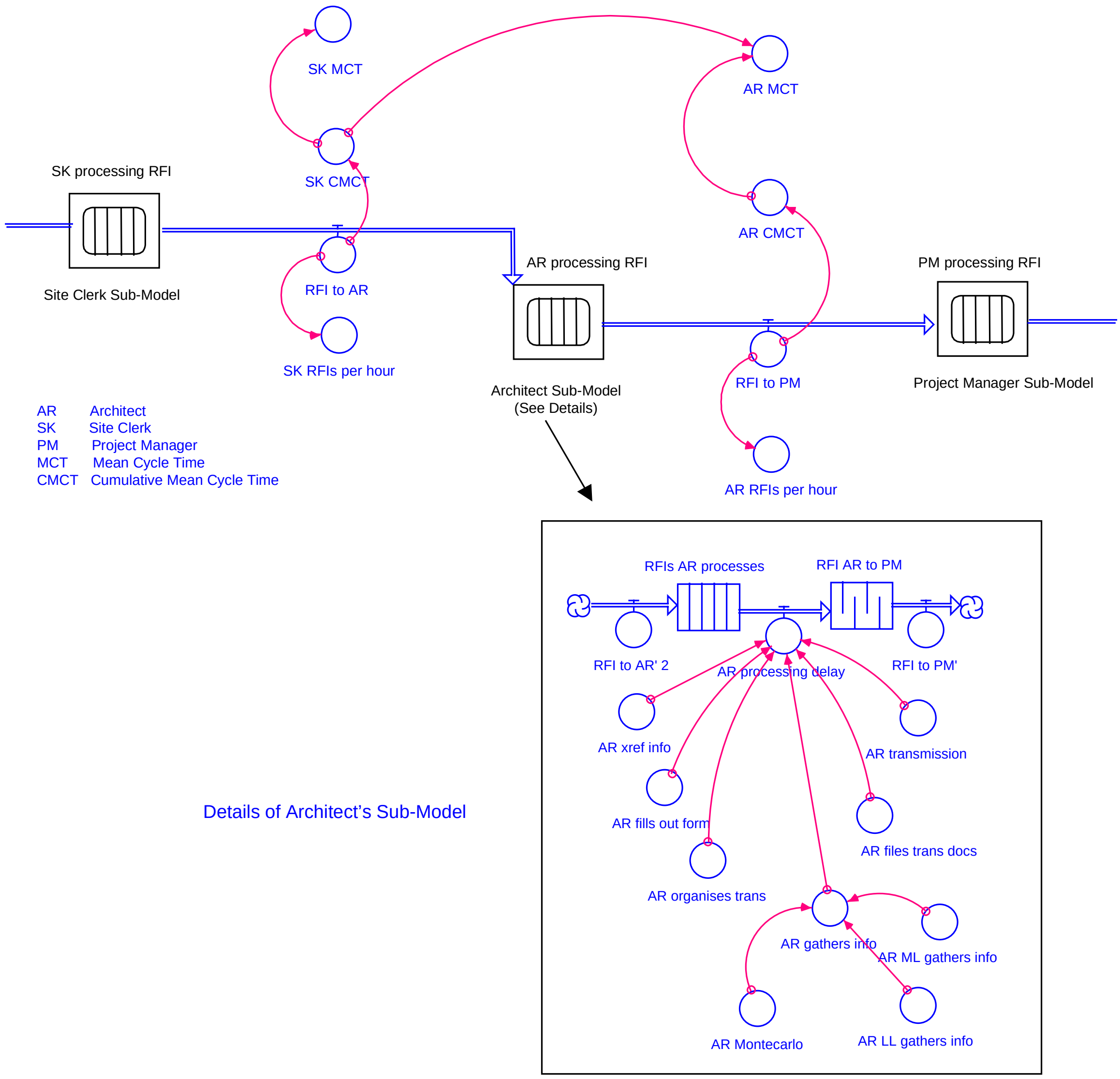

Figure 4: Part of the simulation model showing details of the Architect's sub-model

- percentage of RFIs responded to by the designated date;
- percentage of RFIs which had to be re-sent because the information returned in the initial response did not sufficiently answer the original request;
- percentage of RFIs applicable to more than one consultant;
- percentage of RFIs which constitute a variation to the contract;
- average number of issues raised per RFI form;
- commonly used methods of transmission; and
- shortest (optimistic), greatest (pessimistic) and most likely times to perform individual tasks such as filing responses, filling out forms, etc.

After collating information from survey results, it was decided that the probability (likelihood of occurrence) of re-sending RFIs (due to receiving answers containing insufficient information) is about 13%. This is to reflect respondents' thoughts of current practice. As a result, the number of RFIs generated during the simulation period was increased by such a percentage. *Fig 5* illustrates the concept of increasing the RFIs sent per hour by a set percentage. This figure shows the start of the simulation process, with RFIs being generated then moving onto the Subcontractor's *Sub-Model*.

From a practical viewpoint, the subcontractor is the one who initiates the RFI. However from a modelling viewpoint, the RFI has to have already been generated before anyone can process it. Once an RFI has been generated, it passes through a flow element where it is time stamped, this is an in-built function which enables cycle times to be tracked as the RFIs flow through the model. After being stamped, the RFI is ready to begin its journey through the model. The model is based on a normal distribution of RFIs being generated per unit of time with a generation rate based on the cumulative distribution shown in *Fig 2*.

A Beta distribution was assumed for elements which make up *Sub-Models*. This requires the use of estimated pessimistic, most likely and optimistic values, in a similar way to that used in Program Evaluation and Review Technique (PERT). This distribution has also been used by others (Kangari and Boyer, 1981; Moselhi and Deb, 1993).

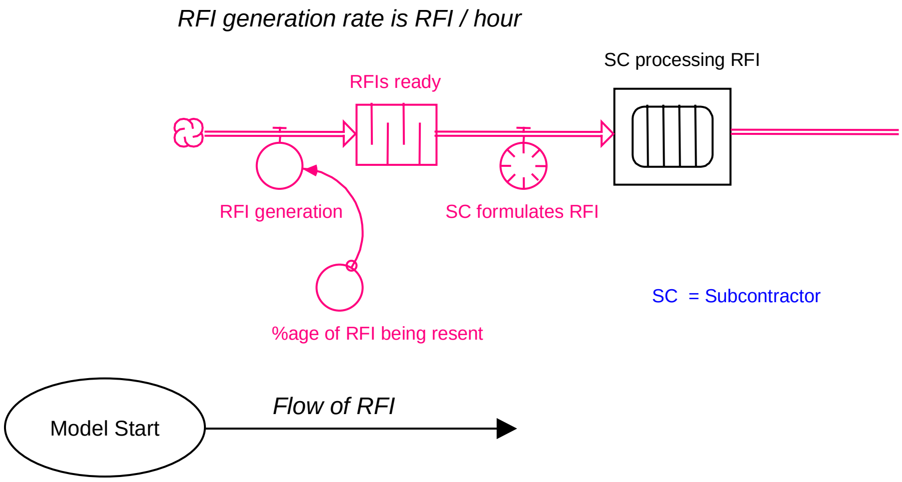

Figure 5: Simulation diagram of RFI generation

Model Validation

An important stage in the development of any simulation model is the validation of the model (Law and Kelton, 1991). During the model development stage, the model was continuously checked through observation of an animated version provided by ithink™. This resulted in confirmation of the model's qualitative conformance to the behaviour of the actual system. Once the model was developed, a more definitive validation was required to confirm the model's quantitative accuracy. The sum of the deterministic most likely values of processing time determined from the survey results (12.3 person-hours) was compared with the model's output without allowing for: (1) stochastic durations, (2) re-sending of RFIs, and (3) variations to the original contract. This process was carried out a number of times, with minor adjustments being made to the model, till the output was considered to have an acceptable level of accuracy. The cycle time obtained from the deterministic simulation was 12.1 person-hours. After this validation, the simulation model was embellished by the stochastic durations for the work tasks reflecting the survey results.

SURVEY AND SIMULATION FINDINGS

Respondents expressed their concern regarding the loss of production and disruption arising from RFIs to resolve document clarification and discrepancies. The general response to the survey made it clear that the majority of architects and designers view the current method of issuing, forwarding and processing RFIs as inefficient. However, they cannot agree whether or not the number of RFIs generated reflects the quality of design and documentation. Designers estimated that the proportion of RFIs being responded to with new drawings ranges from 10% to 25%. A higher proportion was reported for RFIs being responded to with amendments to existing drawings.

The majority of respondents agreed that raising a single RFI that has multiple issues applicable to a range of consultants substantially increases the overall response time. It was also interesting to note that designers requested subcontractors and site managers to put more effort into the issue(s) raised per an RFI to ensure a better response.

Contractors, on the other hand, strongly hold the view that designers need to spend more time on the documentation and be more responsive in acting on the RFIs once received. They also pointed out that 10-25% of the issued RFIs is not responded to by the designated date. Contractors also claimed that about 10% of the responses constitute a variation to the contract.

Both consultants and contractors reacted favourably to adopt a more technologically advanced system to save processing time, however, concerns over security issues and system compatibility were highlighted as major obstacles.

The main result which this research project is concerned with, is the process cycle time. This cycle time can be defined as the (simulated) time required to complete all necessary tasks within the RFI process. The simulation model measures the total time elapsed for one RFI to completely pass through the process. Since the model input was probabilistic, a number of runs were then executed to reach the steady state. This has resulted in a set of mean cycle times representing times spent by individuals processing a single RFI, see *Fig 6*. It should be made clear that each time value, shown in *Fig 6,* represents the aggregate time spent in performing all tasks necessary to process an RFI by the individual.

Fig 6 shows that the architect and superintendent are major contributors to the overall cycle time, which was found to be about 17 person-hours. Their relatively high cycle times are directly related to the estimated duration associated with tasks such as gathering and cross-referencing information. Simulation results were used to estimate the cost associated with the RFI process. Based on current practice, *Table 1* shows the hourly rates assigned to the individuals involved in the process. These rates were then multiplied by the mean cycle times shown in *Fig 6*, to estimate the cost.

Profession	**Hourly rate (A$)***	**Mean cycle time (hrs)**	**Cost (A$)**
Subcontractor (staff)	125	0.56	70
General Foreman	70	1.50	105
Site Clerk	35	1.27	44
Architect	80	5.62	450
Project Manager	100	2.91	291
Superintendent	80	4.66	373
Contract Administrator	60	0.76	46

*A$ = Australian Dollar

Table 1: Summary of simulated time and cost associated with the RFI process

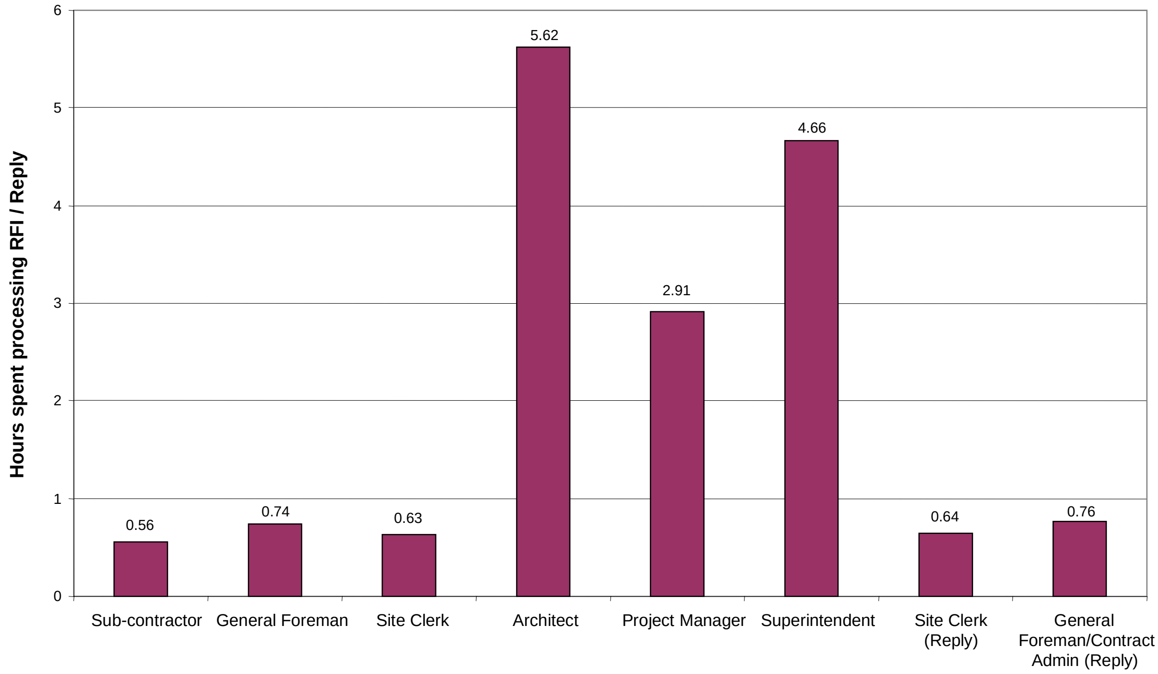

Figure 6: Estimated mean cycle times for processing RFIs and site instructions

ELECTRONIC DATA MANAGEMENT TECHNOLOGIES (EDMT)

Electronic Data Management Technologies (integrated database management system and electronic data interchange) permit users to have all project data stored and managed electronically. It also facilitates the direct computer to computer exchange of data in a standard format. Data is transmitted in some standard format, checked for errors, and then imported directly into the receiving computer system without re-keying (CII, 1993). Such technology is currently employed in the processing of purchase orders, material releases and fund transfers. It is credited with reducing paperwork and data transmission costs, improving data accuracy and enhancing the planning of activities (CII, 1993).

Back and Bell (1995b) demonstrated EDMT potential in improving the workflow for the major functional process of materials management. Aouad et al. (1995) also highlighted the importance of adopting and using such a database, where any changes to information can be recorded automatically within the system, which ensures that every discipline involved is working on the right version of the information.

In the process under investigation, the biggest benefit of EDMT is the reduced time being spent in searching for information that in some way cross-references an RFI. For instance, suppose a subcontractor has issued several RFIs to the engineer over the past few weeks with the majority relating to a particular area of a building, say the Southwest corner. Every time the subcontractor issues an RFI, it has a short description of the subject attached to it, describing it as beam-column connections in the Southwest corner. When the engineer receives another RFI having the subject related to either beam-column connections or Southwest corner, he/she would be able to narrow the database search, listing all other relevant RFIs. Armed with this sort of information, the engineer would be better able to advise the subcontractor on the course of action to take as well as being able to see other consultants contribution, if any, to this problem. Consultants as well as contractors will also have access to this information. EDMT will enable only selected information to be available to a particular person or organisation and prevent those without the authority to direct or modify current or previous RFI information.

Another benefit of EDMT is the reduction in transit time of information between parties. For example, when an RFI is sent via the post, the transit time is the time from when they drop the RFI into the mailbox to the time the addressee has possession of the RFI. The same can be said if the RFI is sent by courier or even fax, there is a transit time from the sending to receiving of the RFI. EDMT, however, reducing this transit time dramatically as parties on the receiving end can be notified immediately when a message arrives at their workstation via a simple on-screen prompt. With the appropriate software, the workstation could also perform a search and not only display the current RFI but also list RFIs previously sent that cross reference the current RFI.

Real-time chat software that is currently widely used by the Internet community could also be employed. A distinct advantage on-line chat has over a telephone conversation is the ability to record and archive written conversations between parties, store these transactions with their corresponding RFIs and cross reference them when the need arises. By having all of this data stored, should there be any legal action taken against anybody involved with the construction process, then there is recorded evidence of who instructed who to do what. At the end of the project, all correspondence for the entire project can be printed, bound and archived, allowing those involved with the project to have both a hard and soft (electronic) copy, fully referenced and indexed ready for later use should the need arise.

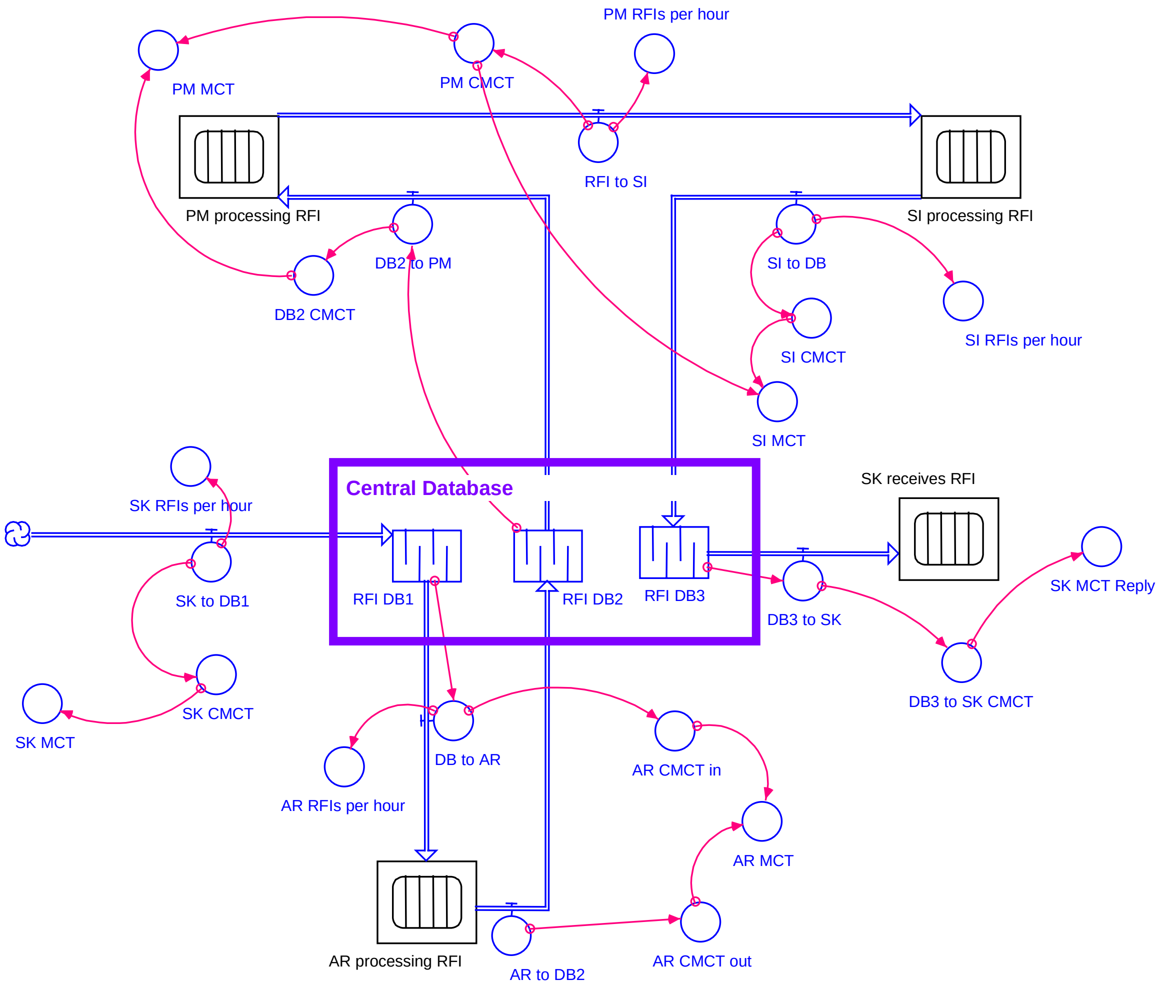

Figure 7: Part of the simulation model with EDMT implementation

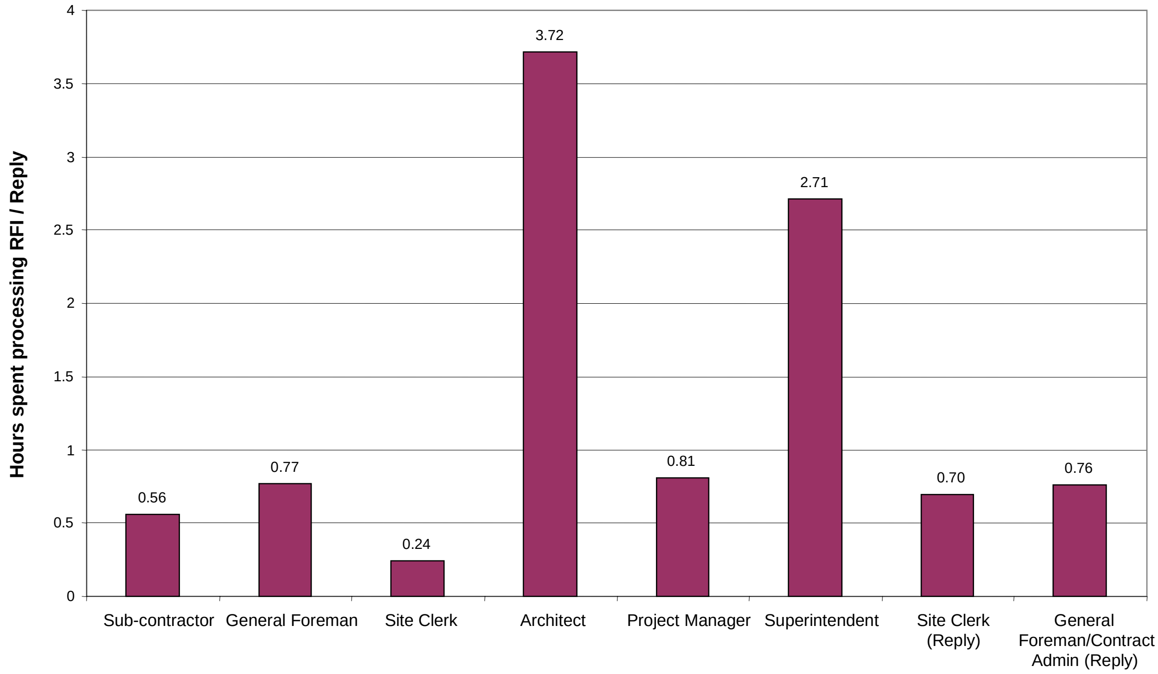

Figure 8: Estimated mean cycle times for processing RFIs and site instructions (EDMT)

CONCLUSION

The prevailing industry practice of issuing and responding to the relatively high number of RFIs issued during the course of a construction project, places additional requirements upon all those who are involved. This might have consequential effects upon production levels and quality. The time and cost associated with the clarification RFI process has been quantified using a simulation model, for a single construction project. Reliance was made on the subjective judgement of personnel knowledgeable about the process being modelled, and survey results were used as model input. Survey respondents expressed clearly their concern regarding the inefficiency of current process and their willingness to adopt a more efficient approach.

Computer dynamic simulation facilitated the RFI process-modelling, capturing the inter-dependencies between the different tasks performed by individuals. The simulation modelling contributed significantly to the quantitative analysis of the process as the model output gave insights into the relatively high cycle times and cost associated with the process. The paper also demonstrated that substantial time benefits of up to 40% could be realised from utilising Electronic Data Management Technologies.

REFERENCES

Aouad G., et al., 1995, The conceptual modeling of construction management information, *Automation in Construction*, **3**, 267-282.

Augenbore, G., 1994, Integrated use of building design tools: results from the COMBINE project, in Tonzis, A. and White, I. (eds.). Automation Based Creative Design, Elsevier Science Publisher, Amsterdam, 205-218.

Back, W.E., Bell, L.C., 1995a, Monte Carlo simulation as tool for process reengineering, *J of Management in Engineering*, **11**(5), 46-53.

Back, W.E., Bell, L.C., 1995b, Quantifying process benefits of electronic data management technologies, *J of Construction Engineering and Management*, ASCE, **121**(4), December, 415-421.

Baldwin, A.N., Thorpe, A., Carter, C., 1996, Simulating the impact of electronic commerce, *Proceedings of the International Construction Information Technology Conference,* Sydney, 199-203.

Bennett, J., Gray, C., Hughes, W., 1994, The successful management of design. Centre for Strategic Studies in Construction, University of Reading, UK.

Bjork, B.C., 1994, RATAS Project–Developing an infrastructure for computer integrated construction, *Computing in Civil Engineering*, **8**(4), 401-435.

Brandon P., Betts, M., 1995, Integrated construction information, E &FN Spon, London.

Construction Industry Institute (CII) 1993, Achieving an integrated data environment: a strategic initiative, University of Texas, publication 20-3, February.

Eastman C.M., Chase, S.C., Assal, H.H., 1994, System architecture for computer integration of design and construction knowledge, in Tonzis, A. and White, I. (eds.), Automation Based Creative Design, Elsevier Science Publisher, Amsterdam, 185-203.

Fisher, N., Yin, S.L., 1992, Information management in a contractor: a model of the flow of project data. Thomas Telford, London, UK.

Gharib, K., 1991, Modelling information flow in a design and build organisation, MSc Thesis, Loughborough University of Technology, UK.

Halpin D., Riggs, L., 1992, Planning and analysis of construction operations. John Wiley and Sons, New York, N.Y.

High Performance Systems Inc. 1994, ithink User’s Guide. HPS, Lyme, New Hampshire, USA.

Kangari R., Boyer, L.T., 1981, Project selection under risk, *Journal of the Construction Division*, ASCE, **107**, 597-607.

Kim, J-J., Ahn, B-J., 1996, Integrating design/cost/schedule information, *Proceedings of the International Construction Information Technology Conference*, Sydney, 163-166.

Law, A. Kelton, W., 1991, Simulation modelling and analysis. 2nd edition, McGraw-Hill Inc., New York, N.Y.

Love, P.E.D., MacSporran, C. Tucker, S.N., 1996, The application of information technology by Australian contractors: toward process re-engineering*, The 4th Annual Conference on Lean Construction*, Birmingham, UK.

Mohamed, S., 1998, Simulation of construction operations: moving beyond traditional operations, *Proceedings of the 6th East Asia-Pacific Conference on Structural Engineering and Construction*, January, Taiwan, 1053-1058.

Morecroft, J.D.W., 1988, System dynamics and microworlds for policymakers, *European Journal of Operational Research*, **35**, 301-320.

Moselhi, O., Deb, B., 1993, Project selection considering risk. *Construction Management and Economics*, **11**, 45-52.

Oloufa, A. A., 1993, Modeling and simulation of construction operations. *Automation in Construction*, **1**(4), 351-359.

Pritsker, A. A. B., 1985, *Introduction to simulation and SLAM-II*. John Wiley and Sons, Inc., New York, N.Y.

Pritsker, A., Sigal, C., Hammesfahr, R., 1989, *SLAM-II network models for decision support*. Prentice Hall, Inc., Enlewood Cliffs, N.J.

Rob, O., Coronel, C., Adams, C.N., 1991, Relational database design at a construction company: a problem or a solution?, *Journal of Systems Management*, **42**(8), 23-27.

Tilley, P.A., 1997, Causes, effects and indicators of design and documentation deficiency, *Proceedings of the 1st International Conference on Construction Industry Development*, December, Singapore, 388-395.

Tommelein, I.D., 1997, Discrete-event simulation of lean construction processes, *Proceedings of the 5th Annual Lean Construction Conference*, Gold Coast, Australia, 121-135.

Vries B de. Somers, L.J., 1995, Message exchange in the building industry. *Automation in Construction*, **4**, 91-1