

# **ARCOM**

## **Doctoral Workshop**

### **IT Research in Construction Management**

Chairman: Professor Ghassan Aouad

6 October 2000  
University of Salford

ARCOM      **The Network of Construction Creativity Club & Doctoral Research Workshop**

IT Research in Construction Management

University of Salford

Friday 6<sup>th</sup> October 2000, 11:00 – 15:30

Chairman : Professor Ghassan Aouad, University of Salford

10:30 – 11:00	Coffee	
11:00 – 11:05	Welcome and introduction to the day	Dr. Andrew Dainty, Coventry
11:05 – 11:10	Introduction to ‘The Network of Construction Creativity Club’	Mr. Norman Gilkinson
11:10 – 11:15	Introduction to IT research in Construction Management	Prof. Ghassan Aouad, Salford
11:15 – 11:40	A Fuzzy Decision Support System for Materials Route in Construction Site	Junli Yang, Wolverhampton
11:40 – 11:55	Discussion and questions	
11:55 – 12:20	IT Tool for Safety Risk Management	Greg Carter, Edinburgh
12:20 – 12:35	Discussion and questions	
12:35 – 13:00	Hazard perception amongst construction workers: Methodological issues using navigable movies and repertory grids.	Guillermo Aranda, Reading
13:00 – 13:15	Discussion and questions	
13:15 – 14:00	Lunch	
14:00 – 14:25	The development of an expert system to manage construction cash flow and associated risks and uncertainties.	Henry Odeyinka, Glasgow Caledonian
14:25 – 14:40	Discussion and questions	
14:40 – 15:05	Towards process improvement in the facilities supply chain	Margaret Nelson, Salford
15:05 – 15:20	Discussion and questions	
15:20 – 15:30	Summary and Conclusions	Prof. Ghassan Aouad, Salford
15:30	Tea & Close	

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# A FUZZY DECISION SUPPORT SYSTEM FOR MATERIALS ROUTE IN CONSTRUCTION SITE

**J.L. Yang and L. Mahdjoubi**

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## **Abstract**

To plan and visualise routes of materials movement in complex construction site is an important consideration in construction project management. The unique complexity of routing materials is burdens on planner and site manager. To address this issue, an study was taken to develop a PC based software tool, named Virtual Construction Material Router (VCMR) that produce sequences of materials routing scenarios based on site layout, available route, activity schedules, and location of temporary accommodation. The core of this system is a GIS-fuzzy based decision-support system, which extends planners experience and assists them make informed decisions to the complexities of time-activities compressed site materials management. This system is to ensure them to select and visualise the most suitable route for materials movement.

## **Introduction**

Reliable predication of materials routing is critical to the success of construction site management. Optimum forecasting for materials movement is an important consideration in the development of an effective project execution planning. This study deals with the implications of materials routing within a complex construction site. Bell and Stukhart (1986) suggested that material management functions include “material requirement planning and material take off, vendor evaluation and selection, purchasing, expenditure, shipping, material receiving, warehousing and inventory, and material distribution.” They emphasise that material management system is concerned with the planning and controlling all necessary effects to ensure that the right quality and quantity of materials and installed equipment are appropriately specified in timely manner, are obtained at reasonable cost, and are available when needed. Construction material management is seemingly divided into a number of issues; which include routing and material scheduling. Material scheduling has received a great deal of attention in construction management research, while material routing in a construction site has, so far, been neglected.

## **Materials management and movement in site**

Great deal of work has been done on material management in scheduling and location. However few research studies have specifically dealt with material routing in construction sites. Muehlhausen (1991) reported that material management as practised in the construction industry, which includes the planning, executing, and controlling of all activities influencing the flow of material to and through job-site, has received a little attention in the application of new technologies. The prevailing tools for planning access are based on models, templates and drawings, which do not facilitate the generation of possible scenarios (Varghese and O'Connor, 1995). Hazem and Bell (1995) suggested that material management systems should be integrated with computer systems that are used for design and scheduling. They proposed an Object Oriented Methodology (OOM) data structure for a materials-management system. McCullouch and Gunn (1993) developed a computer-based material management system. This research claimed that this computer system requires only 26-37% of a field supervisor's time, which can save a great deal of his time and reduce paper work in material management on construction projects. Olusegun, Jacob and Dennis (1998) provided a framework for the development of strategies for improving planning practices. This research links between construction planning and situational factors in the environments within which construction planning is undertaken.

## ***Materials logistic in construction site***

Modern logistic is described as the process of strategically managing the movement or storage of materials, parts and finished, inventory from supplier, through the firm and on to the its destinations (Christopter, 1985). The efficient movement of materials is to increase and meet site demands is often emphasised in the decision making process. McCord and Leu (1995) reported materials routing problem is key point in material logistic where the objectives is to minimise risk and cost form a mutli-attribute utility theory perspective. They explained the assumptions made when posing the cost risk problems as a bi-criterion shortest path problem. It also pointed out the numerical sensitivity analysis carried out on the preference parameter and the shape of the risk disutility function using the road network. It concludes that their model finds several different routes as opposed to one optimal route, under mild uncertainty

assumptions for the model parameters. Although the model is unable to choose a single route, it does succeed in generating a relatively small number of non-inferior paths for representation to the decision makers without soliciting preference information from them.

The most extensive applied work in the materials logistic has been conducted by advanced computer application group of IIASA in Laxenburg, Austria, Weigkrecht and Fedra (1995) mention information and decision support for hazardous materials logistic problems developed at IIASA. This system integrates large database, optimisation techniques, geographic information system as well as effective user interface and computer graphic. This system also will improve decision-making and support quick and effective generation and evaluation of different alternatives.

Mirchandani (1995) considers a neglected aspect of the general materials management problem: the location of inspection stations. Their study gave a set of hazardous materials truck flows in a network. The research is to locate a fixed number of inspection stations with limited inspection capacities to minimise the number of uninspected trucks in the network. It developed several heuristics and reports preliminary computational results by using computer-based decision-making systems.

Another research (Boffey and Karkazis, 1995) has demonstrated by using a non-linear program to select routes for hazardous material delivery in order to minimise risk. They applied a non-linear program to find a shortest path for material. The research is to conclude a condition, which if satisfied, ensures that the linear version of the model finds the same route as the non-linear model. In case the condition is not satisfied, they outline a strategy, based on shortest paths to find the optimal solution to a non-linear model.

Wyman and Kuby (1995) point out that optimisation techniques can be used to quantify the potential saving from new technology which could in turn be used to promote the new technology. It may be possible to find solutions that are superior to traditional solutions for material logistics. Use of location models is to assist decision-makers. This model can be used to restructure the spatial information system dealing with material problems in construction sites.

Decision support system in materials management and routing

Materials management is defined as the management system for planning and controlling all necessary efforts to ensure that right quality and quantity of materials and installed are obtained at reasonable cost and are available when needed (Bell and Stukhart, 1986). Computer-based decision support systems played an important role in material management in maximising construction productivity and reducing materials surplus and time of construction work (Bell and Stukhart, 1987).

Material management decision support system development efforts have been focused on integrating the materials-related functions of quantity takeoff, requisition, purchasing, expediting, transportation, and field materials control and warehousing (Hazem and Lansford, 1996). Meanwhile, integrating decision support systems in materials management has less attention in materials movement in construction sites. Specifically, it is in selection of routes for materials movement.

Fuzzy logic is a scientific revolution that has been waiting to happen for decades and its central tenets will dramatically change the relationship humans have with the real world. In recent years, it has been used for DSS and combined with advanced Information Technology in decision processing. Fuzzy logic systems attempt to model the human reasoning process through a fuzzy set. The reasoning process of a fuzzy set has been captured through fuzzy logic systems in many areas of construction industry such as building design selection (Peak, 1992), resource allocation (Chang et al. 1990), CAD design control (Campo, 1995).

Feng and Xu (1999) have developed an integrated system in which knowledge-based decision systems; artificial neural networks and fuzzy systems are used for urban development. On the other hand, Hanna and Lotfallah used a fuzzy logic approach to select the suitable crane type in construction projects. This system uses fuzzy logic techniques to aid contractors to optimise the selection of crane types.

Fuzzy approaches have dominated research in computerised construction management. Yu and Skibniewski developed (1999) a multi-criterion decision model for quantitative constructability analysis, which is based on a neuro-fuzzy knowledge. They suggest that with this system, the constructability can be quantified, measured and improved. It also incorporates construction manager's subjective preference information. They have used a neuro-fuzzy network-based approach in providing a mechanism to trace back factors causing unsatisfactory construction performance and the necessary feedback to construction engineers for technology innovation (Yu and Skibniewski, 1999).

The construction industry has attempted to apply these modern information technologies to such as its project management and cost control. Using fuzzy logic to select suitable design approaches was developed at the University of Nebraska NE (Peak, et al. 1992). It suggested that a multicriterion decision-making methodology could be applied for selecting the best design/build proposal under uncertainty which relates the high technical factors and low construction cost. Jeljeli and Russell (1995) suggested that use of decision analysis approaches is to cope with



The geometry and its spatial attributes are subsequently stored in a database management system (i.e. Ms Access) in a text format. As work on site progresses, thematic data relating to site spatial attributes can be revised and updated through a user interface, as shown in figure 3. This information is updated and then stored in the DMBS.

This information is stored in a DBMS ready for visualisation and presentation. It is possible to execute the query function in AutoCAD MAP. The selected nodes could be linked and

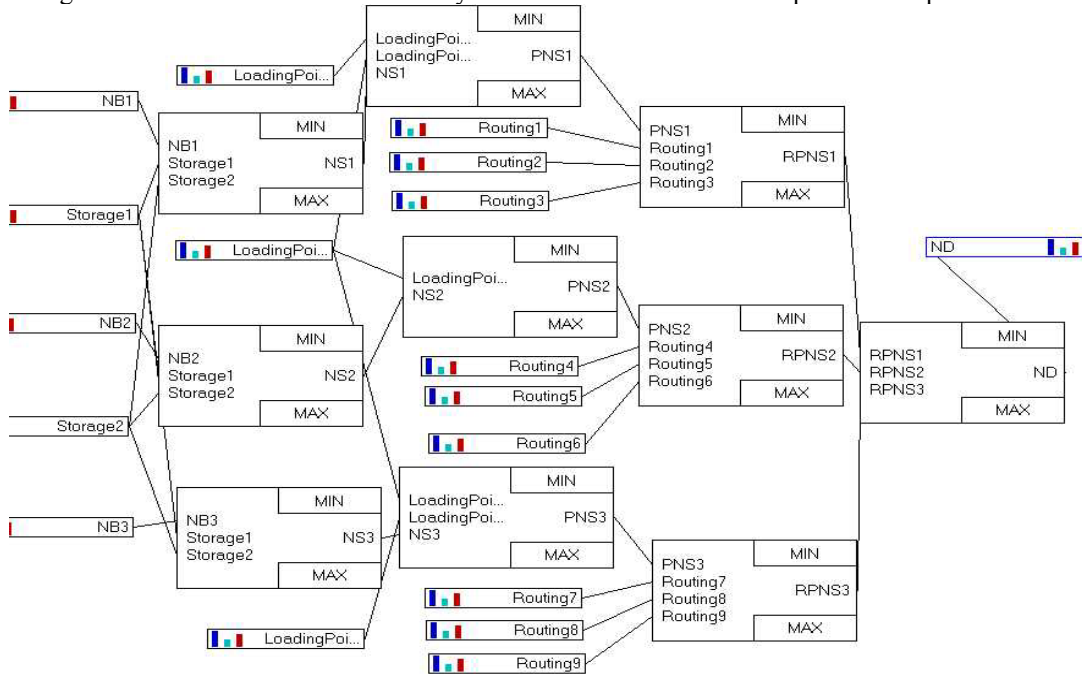
**Figure 2 A completed site layout**

redisplayed in AutoCAD Map. This graphical representation will enable site managers and planner to identify possible conflicts of material movement and activities. It also allows the rehearsal of various scenarios.

**Figure 3 DBMS in VCMR**

**Results**

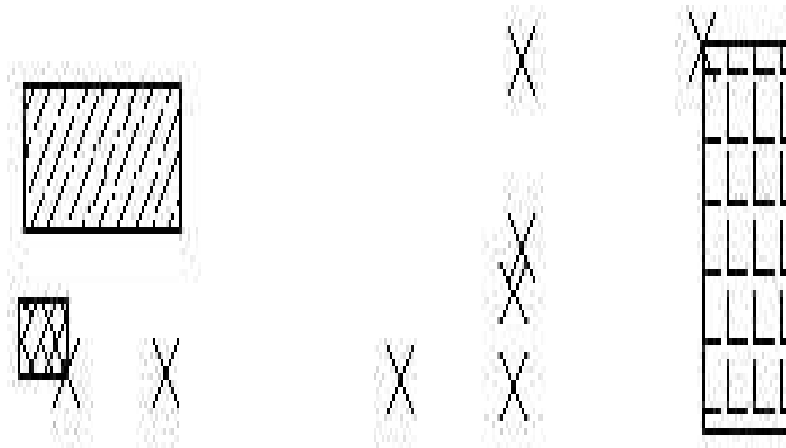
A prototype of VCMR intelligent routing selection system has been developed. The routes are produced by the decision-making system (figure 4), which use a rules based fuzzy logic system to process the input criteria of routing. User defined criteria are selected or entered through a VRMC interface to supply the analytical queries. This includes destination of materials, types of materials, date and time, and materials storage locations (figure 5). Figure 6 and Figure 7 show a visualisation created by the VCMR for criteria-set output in a complex construction sites.



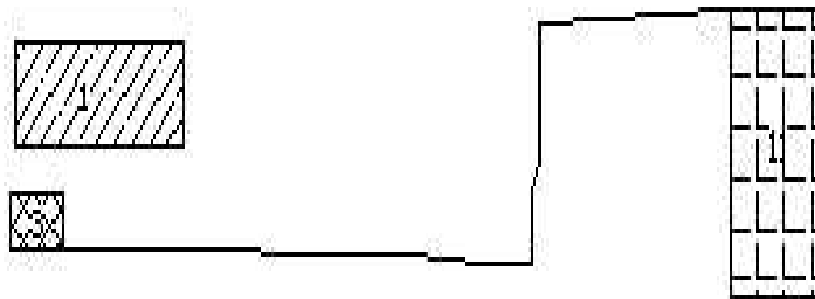
**Figure 4 Fuzzy logic decision-making system in VCMR**

**Figure 5 Criteria entry and selection in VCMR**





**Figure 6 Related nodes of routes**



**Figure 7 Route for material movement**

## Conclusion

The GIS- fuzzy logic based decision support tool that is described in this paper is in an ongoing research project. The prototype currently implemented is functional systems only in few limited senses. The decision support system based on site information, which considers the spatial allocation, scheduling and sequence of construction activities. While results presented here are preliminary, there is a guarded optimism about the potential of the system (Virtual Construction Material Router). With further development system, it is believed that use of this system will be able quickly to perform selection of criteria and simulate the final route of material movement in a visualisation package. Also there is an expectation that effective querying system will ensure the route displayed automatically.

## References

- Bell, L. C. and Stukhart, G., (1986). Attributes of materials management systems. *Journal of Construction Engineering and Management*, 112(1), pp14-22.
- Bell, L. C. and Stukhart, G., (1987). Cost and benefits of management system, *Journal of Construction Engineering and Management*, 113(2), pp222-234.
- Boffey, T.B. and Karkazis, J., (1995) Linear versus nonlinear model for hazmat routing, *Info*, Vol33(2), pp114-117.
- Chang, T.C., William, C. and Crandall, K.C., (1990). Network allocation with support of fuzzy expert system, *Journal of Construction Engineering and Management*, 116(2), pp239-259.
- Christopher, M. (1985), *The strategy of distribution management*, Gower publish.
- Chua, D.K.H., Kog, Y.C., Loh, P.K. and Jasflskis, E.J., (1997) Model for construction budget performance-Neural network approach, *Journal of Construction Engineering and Management*, 123(3), pp214-222.
- Faniran, O.O., LOVE, P.E.D., and Li, H. (1999). Optimal Allocation of Construction Planning Resources. *ASCE Journal of Construction, Engineering and Management* 125(5), pp.311-319.

- Hanna, S. and Lotfallah, W. B., (1999). "A fuzzy logic approach to selection of cranes." *Automation in construction* Vol. 8 pp597-608.
- Hazem, E. M. and Bell, L. C., (1995). Object-oriented methodology for material management system. *Journal of Construction Engineering and Management*, 121(4), pp438-445.
- Jeljeli, N. and Russell, J., (1995). Coping with uncertainty in environment construction: Decision analysis approach, *Journal of Construction Engineering and Management*, 121(4), pp370-380..
- Maccullouc, B. and Gunn, P., (1993). Construction field data-acquisition with pen-based computers. *Journal of Construction Engineering and Management*, 119(2), pp374-384.
- Mahoney, J. J. and Tatum, C. B., (1994). Construction site application of CAD. *Journal of Construction Engineering and Management*, Vol.120, No.3, pp617-631.
- McCord, M.R. and Leu, A.Y-C, (1995). Sensitivity of optimal harmat routes to limited preference specifications, *Info*, pp68-83.
- Mirchandani, P.B.,Rebello, R. and Agnetis, A. (1995), The inspection station location problem in hazardous materials transportation:some heuristics and bounds, *Info*, Vol 33(2), pp100-113.
- Muehlhausen, F. B., (1991). Construction sites utilisation: impact of material movement and storage on productivity and cost, in *Transaction of the American Association of Cost Engineering*. 1991 L-2, pp1-9.
- Olusegun, O. F., Jacob, O. O. and Dennis, J. L., (1998). Interactions between construction planning and influence factors. *Journal of Construction Engineering and Management*, 124(4), pp245-256.
- Papadias, N. K. and Arkoumanis, D., (1999). " Processing fuzzy spatial quires: a configuration similarity approach," *INT. J. Geographical Information Science*, Vol.3, NO: 2, pp93-118.
- Peak, J.H. and Lee, Y. W., (1992). Selection of Design/Building Proposal Using Fuzzy-Logic System, *Journal of Construction Engineering and Management*, 118(2), pp303-317.
- Robbins, S. R., (1991). *Management*. 3<sup>rd</sup> ed. Englewood Cliffs, NJ: Prentice-Hall.
- Tommelein, D., (1994). Materials handling & site layout control. 11th Int. Symp. Automation and Robotics in Construction, pp297-304.
- Varghese, K. and O'Connor, J. T., (1995). Routing large vehicles on industrial construction sites. *Journal of Construction Engineering and Management*, 121(1), pp1-12.
- Varghese, K., (1992). Automated route planning for larger vehicles on industry construction sites. Faculty of the Graduate School of University of Texas at Austin.
- Weigkricht, E. and Fedra, K. (1995). Decision support system for dangours goods transportation, *Info*, Vol 33(2), pp84-99.
- Wyman, M.M. and Kuby, M. (1995), Turning the table: using location science to specify technology rather than allowing technology to constrain location: a commentary, *Info*, Vol 33 (2), pp118-122.
- Yu, W. D. and Skibniewski, M. J., (1999). "A neuro-fuzzy computational approach to constructability knowledge acquisition for construction technology evaluation." *Automation in construction*, Vol.8 pp539-552.

# IT TOOL FOR SAFETY RISK MANAGEMENT

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## Abstract

In December 1999 the University of Edinburgh and Carillion initiated a project to investigate the topic of construction safety risk. The overall aim of this research is the development of an IT tool to assist in the management of construction safety. An integral part of this tool will be a knowledge base representing the combined knowledge and experience of all personnel within the company.

An extended site visit was conducted for familiarisation with existing company methods, data collection and, working closely with safety personnel on-site, developing initial ideas and proposals for the final IT tool.

This paper reports current progress in its development. The prototype discussed in this paper is intended for research purposes to develop and test ideas that may provide assistance in the safety risk management process. Many grey areas exist regarding the precise structure and operational requirements of the final IT tool but some initial ideas and proposals are presented. The paper goes on to provide a brief outline of future work.

## Prototype risk log application

Most drawbacks of existing risk logs stem from the fact that risk ratings are based upon individual estimations and opinions, which makes them very subjective in nature and susceptible to an individual’s ‘risk propensity’. Greene (2000) describes this subjective assessment of risk in more detail.

The proposed risk log uses historical data to establish the risk associated with each hazard. Thus risk can be evaluated quantitatively rather than estimated qualitatively. The risk rating will vary depending upon the actual safety situation on-site because it is calculated from accident/incident data and updated as accidents/incidents occur.

Data from accident/incident reports and existing risk ratings were analysed. Although, at present, only a small number of accident/incident reports are available to us the results of the analysis indicates that there is a variance between the datasets (Table 1). These preliminary results indicate that the existing subjective method of assessing risk does not correspond to risk determined from historical data and thus does not reflect the risk that operatives are actually exposed to on-site.

**Table 1** *Analysis of existing and proposed risk rating method*

Hazard	Existing risk rating (based upon subjective estimation)	Proposed risk rating (based upon historical data)	
		Mean	Range
Strike buried services	6.0	11.6	10 – 14
Manual handling	9.0	10.7	10 – 12
Trespass/vandalism/theft	4.0	10.0	10
Struck by moving plant	8.0	10.0	10
Slips/trips/falls	12.0	11.6	10 – 14
Power tool accident	12.0	10.0	10
Proximity to live OLE	6.0	10.0	10
Damage to existing infrastructure	5.0	10.0	10
Contamination/pollution	3.0	10.0	10

## Results of ANOVA analysis

Parameter	Existing rating	Proposed rating	Summary
Average	7.111	10.433	
Variance	11.361	0.490	
F-value			8.382
F-critical			4.494
P-value			0.011

While it is true that an element of uncertainty exists in any assessment of risk, due to the fact that we are trying to predict future events, it is also true that providing a historical and factual basis for assessing risk can reduce the degree of uncertainty. Building a database of accidents will allow objective measurement of accident frequency and severity, which should lead to a more objective assessment of risk.

Feedback on safety performance will be incorporated into the risk log. This will put the numerical risk ratings into context and effectively flag the hazards that have an undesirable level of risk associated with them, which will highlight areas for improvement. Cameron (2000) has previously used safety performance scores and visual feedback in the field of behavioural safety and states that such feedback and goal setting stimulates motivation for continuous improvement. We propose that safety performance is assessed via consideration of the risk reduction rate and the final risk level for a hazard. Data will be presented in graphical form so that the user can view the historical data and the trends used to predict future performance. Target levels for risk, based upon safety performance, can be assigned so that risk reduction becomes a fundamental aspect to the risk log.

### Final IT Tool proposal

#### Overall Design Structure of the IT Tool

The IT tool will have a three-tiered structure (Figure 1). The first tier is the client side of the system and will be a windows-based user interface, which represents the only ‘visible’ part of the tool. The third tier will be a database containing the combined knowledge and experience of all personnel within the company. The second tier will consist of an application that can take a client request, interrogate the database and return it to the client side of the system. Knowledge Discovery in Databases (KDD) and Data Mining (DM) tools could be incorporated into this second tier to aid in data extraction and analysis processes.

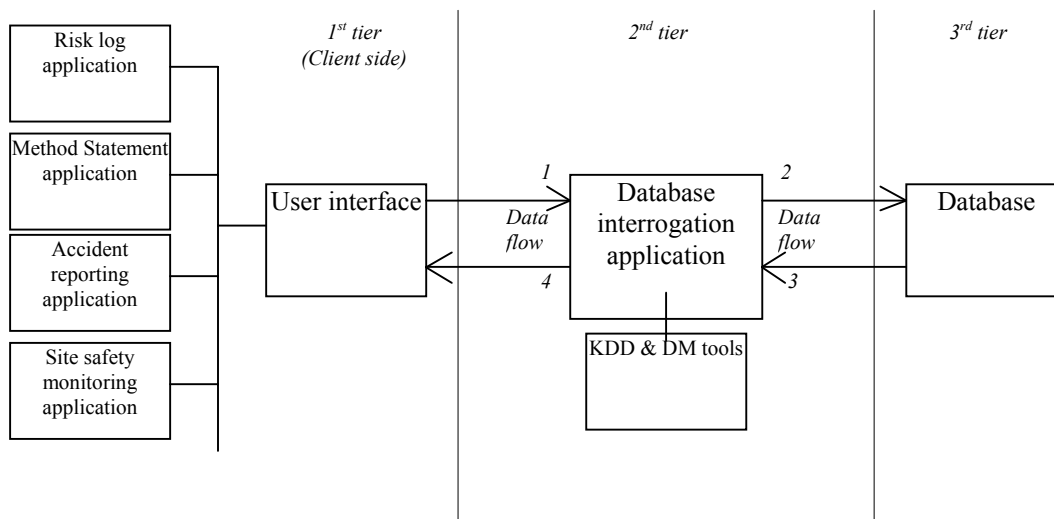
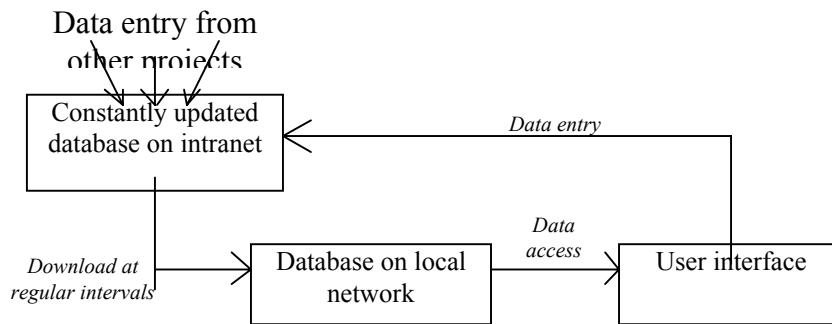


Figure 1 Proposed design structure of the IT tool

#### Database Management

Database management is recognised as being fundamental to the final IT tool. Data entry and access to up-to-date information represent two important operational features. A possible solution for medium to large projects, i.e. those likely to have their own servers on-site, may be to transfer the company’s centralised database from the intranet to the local network drive for each individual project (Figure 2). Storing the database on the intranet will allow data from all projects to be sent to one single location thus solving data entry and storage problems. Downloading the database to each project’s localised network reduces the effects of two common problems of accessing data on an intranet, i.e. multi-user access and bandwidth limitations. However, the database will need to be re-downloaded at regular intervals throughout the project duration to make sure that personnel always have access to up-to-date information.



**Figure 2** *Proposed method of database management*

### Current & future work

Work is also being carried out on the topic of Method Statements. Studies are focussing on hazard identification. The results of these studies will be used to improve: 1) the Method Statement preparation process, 2) the generation of risk assessments from project risk logs and 3) linking of risk assessments and methodologies via hazard referencing. In terms of the risk log developments, analysis of the data gathered on-site will continue for a couple of months. Results from this data will lead to further advancements regarding the prototype application. The other main components of the user-interface, indicated in Figure 1, will also be developed over the next few months. Field trials will then be conducted to test the IT tool.

### References

Cameron, I. (2000) Total Safety Management: A Benchmarking Framework. *Network of Construction Creativity Clubs: Seminar at the 16<sup>th</sup> Annual ARCOM Conference*, Glasgow Caledonian University, Glasgow.  
[www.ce.strath.ac.uk/nccc/NCCC\\_Communications/Case Studies/Case study\\_34.zip](http://www.ce.strath.ac.uk/nccc/NCCC_Communications/Case Studies/Case study_34.zip)

Greene, A., Root, D. and Thorpe, T. (2000) The Comfort Blanket of Risk Assessment: An Investigation into the Subjective Assessment of Risk. *Proceedings of the 16<sup>th</sup> Annual ARCOM Conference*, Glasgow Caledonian University, Glasgow, **1**: 241-249

# A STUDY OF HAZARD PERCEPTION AMONG CONSTRUCTION WORKERS: ADDRESSING METHODOLOGICAL ISSUES OF USING NAVIGABLE MOVIES AND REPERTORY GRIDS

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## Abstract

This paper aims to understand how construction site users categorise hazards of their own working environments. The principal focus of this paper is the elicitation of hazards and their relationship to working systems in terms of perceived danger, as they might affect decisions regulating design, management and training considerations. The study was undertaken in laboratory conditions, the participants were presented with simulated scenarios of their everyday working environment using navigable movies. The interviewing mechanism was the repertory grid technique.

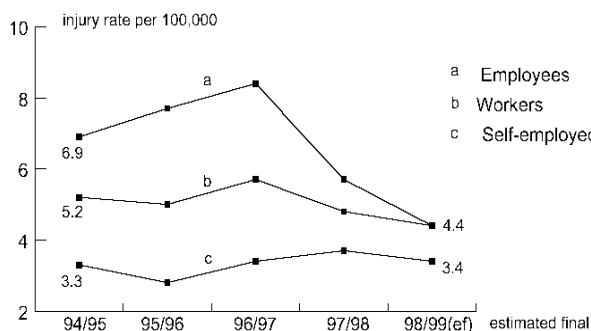
Keywords: subjective perception of hazards; navigable movies; repertory grids; qualitative data collection

## Accidents in the work place

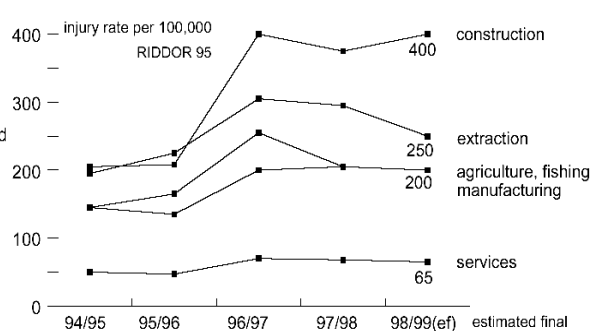
The interest in safety awareness among construction professionals within the UK has increased in the past five years. Several mechanisms were implemented to deliver a safer working environment for construction employees. These include: The Construction, Design and Management Regulations (Williams 1996), training programs and safety campaigns, all forming part of the Government's agenda to reduce the number of accidents that occur within the industry.

Statistical figures from the Health and Safety Executive (1999) show that in 1994-95, the year prior to CDM, there were 88 fatalities in the industry and 2627 major non-fatal injuries. Four years on, the latest for which statistics are available, fatalities had dropped to 70 - the lowest figure for two decades (see fig.1)- but the number of notified accidents had actually risen to 4169.

The non-fatal-major injury rate for employees is expected to be 399.2 per 100,000, almost as twice that for 1995/96. According to the HSE this is a consequence of *under-reported* accidents prior RIDDOR '95 reporting regulations (1999). Although statistical figures draw a blurred picture of assessing the industry's safety record, if compared to four or five years ago, it is clear that the number of fatalities has decreased, but major-non-fatal accidents has increased (see fig. 2)



**Fig 1. Fatal injury rates in Construction, H&S Executive 1998/1999**



**Fig 2. Non-fatal major injury rates to employees by industrial sector, H&S Executive 1998/1999**

The statistics seem to suggest that accidents can migrate and reappear within the system in different form and degree, e.g. the latest figures show that there are less fatalities but the number accidents has increased to reach its highest point since 1996, when the CDM regulations were introduced.

An assumption to this phenomenon is that underlying behavioural processes exists, thus when safety systems are introduced might be effective but in the long run, users will *compensate* their risk taking behaviour and accidents will come back in different form and degree. Research in fields away from construction have identified this behavioural phenomenon, some emergent theories include: risk compensation theory (McKenna 1988), risk homeostasis theory (Wilde 1988), zero-risk theory (Summala 1988), subjective expected utility (von Newman 1947), sensation seeking (Eysenk 1983), of which some have been successfully implemented in economics, i.e. insurance companies (Bell 1984) and transport, i.e. reducing car accidents (Parker 1992).

So far, the main systems which attempt to safety in the UK construction industry have not consider the repercussion in the Success or failure of the current safety system in the UK's construction industry might be highly affected by this behavioural reaction to system modifications however it has being ignored in the over all scope, including: design of physical safety systems, management, legislation and safety training.

### **Human response to hazards**

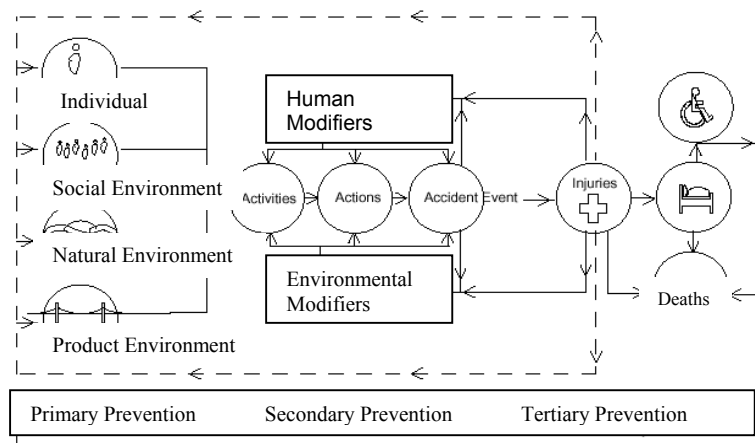
In order to study the risks associated with construction work it is essential to have a valid model of an accident. A number of models have been proposed on how an accident takes place (Rockwell 1967; Lee 1981; Slovic 1981; MacGill 1986); the model on fig. 3 firstly was developed by the Australian Child Accident Prevention Foundation and has been adapted by the Home Accident Surveillance System (Pearce 1986). This particular model brings a clear and comprehensive picture of how accidents occur thus the reason to adopt it.

A typical accident in the built environment is a process, not a single isolated event (Pearce 1986), and this brings us to look at 'the accidents event' from a much broader social scope i.e. the victim's number of children. Applying the model, one could start analysing the stable background features of the individual:

- The person: refers to personality, intelligence, expertise, social background, age, sex, income and resources, family structure.
- Social environment: neighbourhood, work atmosphere,
- Natural environment: topography, time of the day, weather.
- Product environment: these are features of the product itself (i.e. a house, a tool), its design, its age, type and condition.

Usually an activity relates the person to the product: an operative is using a power tool or some piece of equipment, and the activity is associated with temporary influencing factors which may be human stress, fatigue or the environment in which this person is working in. Poor design features of the product may lead to a propensity to an accident.

Human and environmental modifiers are mechanism that exist to avoid accidents, they are positioned in the area of secondary prevention, these focus on minimising injuries when the accident does take place, for example wearing the hard-hat or other protective equipment and try to make sure that people are hurt as little as possible if an accident takes place. Human modifiers deal with areas of supervision, development of knowledge skills, training systems whereas environmental modifiers look at legislation of behaviours, product safety codes, product instructions, safety devices, and social policy.



**Fig 3. The Accident/ Injury Process Model, modified from the: Australian Child Accident Prevention Foundation.**

### The Technique

Repertory grid technique is closely related to the personal construct psychology developed by George Kelly (Kelly 1959), it views people as enquirers and inventors of their worlds. Although it is comprehensive, it does not seek to completely define the psychological world but enables a discourse in the process; that is, the typical ways they make representations of the social/emotional environments and the assumption is that these internal representations largely determine people's representations.

These representations are established by a procedure known as 'dyadic and triadic elicitation'. The participants were exposed to three virtual scenarios of their own workplace, and asked which two are alike and unlike the third. They were also asked for the reasons for similarity and dissimilarity. The reason given for two places being similar and different from a third becomes a bipolar construct (e.g. a safe workplace- a dangerous workplace). The process is then repeated with a further group of places and a second bipolar construct is elicited. Further groups of three different places at work are presented until the subject's repertory of constructs distinguishing the object is exhausted.

User behaviour will partially be a function of the cognitive schemata by which participants represent features, functions and operations of their environment (Kelly 1959; Maher 1969; Mair 1988). By using the repertory grid technique this investigation aims to explore the following two questions: (1) how site operatives and construction workers view hazards at work (2) How could those representations vary when the system/situation has been modified.

An interactive multimedia tool was designed to simulate the place under scrutiny on a distance basis, in this way triads with participants were carried in a room context avoiding site disruption and reducing travel costs, but more, important it was possible to expose participants to the same environmental conditions including: place and event.

Video simulated environments have been widely used in psychological research as powerful tool to control situational variables (Horswill 1994). The interactive tool designed for this study is based on the use of *navigable movies* also known as still-video. In the context of the built environment, navigable movies fulfil the need of visualising existing environments, they are based on photographic images as such they provide a reliable source of information avoiding the linearity and passiveness of traditional video.

Identified advantages of the use of navigable movies over other visual media:

- They indicate desired as well as undesired aspects of a building site, situations of interest can easily be reproduced; this is because they are based on photographic techniques.
- They simulate a distant location introduced in a room context.
- They allow exploratory interface, capturing situations on time and users can explore scenarios.
- Egocentric interface, this means that scenarios are explored at the users will.
- They show 'what is there' but not how or since when, this is because they are not showing physical actions.
- As with digital photographs, elements in navigable movies could be introduce/remove

### Procedure

Description of the place of study:

New headquarters office development of 38,000 sq ft in the Thames Valley, UK.

Building stage: structure erecting, cladding, roofing and building services installations



Contractor: Wates Construction

Priming participants: 15 construction workers with a minimum of two years of work experience were invited to participate in the study, they were called -by the site manager- and asked if they could spare an hour to interact with multimedia videos and to discuss safety at work -the study was carried on an individual basis.

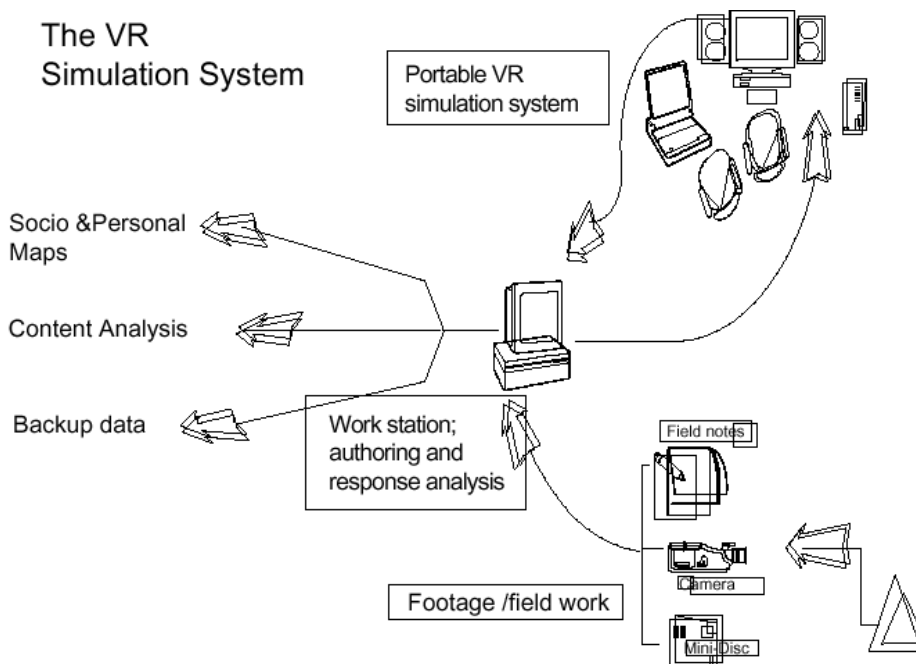
Participants included: electricians (2), carpenters (2), plumbers (2), bricklayer (2), scaffolders (2), steel erectors (2), concreters (2), forklift operative (1). Characteristics: all where British, all where male, non of them had suffered any serious accident. The most experienced participant was a scaffolder with 23 years within the trade; the least experience was a bricklayer with two years within the trade.

**Procedure:**

Firstly participants had to explore the various places of investigation on a simulated walkthrough, a bird-eye navigation map indicated the various points to be explored.

On a second stage, randomly sorted groups of movies -done by the repertory grid program- where shown to the participant, the scenarios were chosen so as to cover a wide variety of site characteristics. Participants where presented with sets of three site locations at the time. Then, they were asked to name a similar aspect of two locations and a different one from the third location in terms of safety at work- in other words, what made the two they selected similar and what made them different from the third. Details of the responses are listed as the two poles in the bipolar constructs. This process was be repeated with various combinations until all the existent scenarios where clearly differentiated.

Element rating: A third stage is when all elements where rated from 1 to 7 using the constructs as reference points, in this case if we had five places as elements and five bipolar constructs a matrix table of five by five with ratings was formed by each participant. Grids can be analysed individually or compared with other grids to define links and similarities between individuals and groups. The interviews were also recorded as a means of grids back up.



**Fig 4. The simulation system: image capture, authoring, delivery and processing mechanisms.**

Five movies were embedded to the repertory-grid program originally developed by Gaines Shaw (Gaines 1980; Shaw 1990). The resulting system is a desktop interactive tool that enables the participant to explore the scenarios in a random way and elicit constructs. The procedure of sorting the movies through the program eliminates the inconvenience of having to arrange the movies in a manual way. The method has shown to be non-threatening to the participants since navigation does not require computational skills- and enables a more convenient way to capture responses for the facilitator.

## Results

The analysis of various working scenarios was used to elicit constructs from construction workers with the aim to have a better understanding of how they perceive and classify hazards at their work place; in this way it was possible to examine their beliefs and attitudes.

Analysing the repertory-grids it was identified that participants created two groups of constructs: physical constructs and emotional constructs. Physical constructs were those related to the place, e.g. need to wear protective gear, bad weather conditions, need for demarcation systems, noise pollution. Emotional constructs were related to situational events including: stress, work climate and incentives, management style, level of expertise.

The responses have been grouped into the following three main groups:

- The place: physical attributes of the work-place
- The people: stress and incentives
- The organisation: safety communication.

It was found that some safety procedures – including some training programs - aim at narrow targeted areas-, it is believed that accident reduction requires a long term commitment.

## Bibliography

- (1999). Safety and Enforcement Statistics. London, Operations Unit, Health and Safety Executive.
- (1999). Safety statistics bulletin, Health and Safety Executive.
- Bell, D. E. (1984). "Putting a premium on regret." *Management Science* **31**: 117-120.
- Eysenk, H. J. (1983). A biometrical-genetical analysis of impulsive and sensation seeking behaviour. *Biological bases of sensation seeking, impulsivity, and anxiety*. M. Zuckerman. Hillsdale, N. J., Erlbaum.
- Gaines, B. R. (1980). *On becoming a personal scientist*. London, Sage.
- Horswill, M. S. (1994). An investigation into the use of video simulation techniques for measuring driving behaviour. *Dept. of Psychology*. Reading, The University of Reading: 337.
- Kelly, G. (1959). *The psychology of personal constructs*. New York, Norton.
- Lee, T. R. (1981). "The public's perception of risk and the question of irrationality." *Proc. R. Soc. London*: 3-16.
- MacGill, S. M. a. B., F.G. (1986). Understanding risk perception; conceptual foundations for survey based research. Leeds, U.K., University of Leeds: 41.
- Maher, B. (1969). *Clinical psychology and personality: the selected papers of George Kelly*. New York, Wiley.
- Mair, M. (1988). Kelly, Bannister and a story telling psychology: 8.
- McKenna, F. P. (1988). "What role should the concept of risk play in theories of accident involvement." *Ergonomics* **31**(4): 469-484.
- Parker, D., Manstead, S.R., Stradling, S.G. (1992). "Intention to commit driving violations: an application of the theory of planned behaviour." *Journal of Applied Psychology* **77**(1): 94-101.
- Pearce, N. H. a. E., S. E. (1986). *Perception of risk, myth and reality*. Bristol, Safety office/ University of Bristol.
- Rockwell, T. H. a. B., L.R. (1967). "Information seeking in risk acceptance." *Journal of the American Soc. of Safety* **13**: 6-11.
- Shaw, G. (1990). *Rep Grid Manual*. London, Center for Person Computer Studies.
- Slovic, P., Fischhoff and Lichtenstein, S. (1981). "Perceived risk: psychological factors and social implications." *Proc. R. Soc. London*: 17-34.
- Summala, H. (1988). "Risk control is not risk judgement: the zero-risk theory of driver behaviour." *Ergonomics* **31**(4): 491-506.
- von Newman, J. M., O. (1947). *Theory of games and economic behaviour*, Princeton University Press.
- Wilde, G. J. S. (1988). "Risk homeostasis theory and traffic accidents: propositions, deductions and discussion of dissension in recent reactions." *Ergonomics* **31**(4): 441-468.
- Williams, B. T., D. (1996). *The CDM regulations: A design and risk assessment manual*. UK.

# THE DEVELOPMENT OF AN EXPERT SYSTEM TO MANAGE CONSTRUCTION CASH FLOW AND ASSOCIATED RISKS AND UNCERTAINTIES

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## **Background**

The major problem that construction managers encounter in making financial decisions involves both the uncertainty and ambiguity surrounding expected cash flows (Eldin, 1989). In the case of complex projects, the problem of uncertainty and ambiguity assumed even greater proportion because of the difficulty in predicting the impact of unexpected changes on construction progress and consequently, on cash flows (Boussabaine and Elhag, 1999). The uncertainty and ambiguity are caused not only by project-related problems but also by the economical and technological factors (Laufer and Coheca, 1990). Lowe (1987) argued that the factors responsible for variation in project cash flow profile could be grouped under five main headings of contractual, programming, pricing, valuation and economic factors. Harris and McCaffer (1995) and Kaka and Price (1993) identified the factors that affect capital lock-up, which ultimately affect project cash flow profile. The identified risk factors have been reported to affect cash flow profiles as well as significantly impacting on the modelling of cash flow. However the perception of the contractors to the likelihood of the risk factors occurring in different project types and of varying scope and duration is yet to be investigated. This then is one of the concerns of this study, which intends to develop a knowledge-based expert system to manage construction cash flow and associated risks and uncertainties.

## **Aim of the Research**

The aim of the research is to investigate the uncertainties and risk factors inhibiting an accurate forecast of construction cash flow. Based on an analysis of these factors, the research aims to develop a modular computer based expert system to forecast and manage construction cash flow.

## **Objectives**

1. To identify and assess the uncertainty and risk factors involved in modeling construction cash flow forecasting;
2. To develop typologies of cash flow forecasting models based on classification categories suggested by analysis of risks and uncertainties involved in cash flow forecasting;
3. To construct an expert system model for the management of construction cash flow;
4. To develop a prototype expert system to manage construction cash flow;
5. To implement the developed system and test its forecasting accuracy.

## **Research Methodology**

### **1.1 Stage 1 (Objectives 1& 2)**

In order to identify and assess the uncertainties and risk factors involved in modeling construction cash flow forecast, a questionnaire survey of construction contractors was carried out. The survey assessed the perception of the construction contractors to the likelihood of occurrence and impact of uncertainties and risk factors involved in modeling cash flow forecast. Data from the survey was analyzed using 'mean response' ranking and univariate analysis of variance. Results showed that there were significant differences of contractors' opinions on major risk factors when analyses were carried out based on the groupings of size of firms, construction duration and procurement options. This preliminary result suggests that modeling of cash flow forecast may need to consider modeling along those groupings in order to accommodate risks and uncertainties.

In order to develop typologies of construction cash flow models based on the classification categories suggested by analysis of inherent risks and uncertainties, it is proposed that a case study approach would be utilized. Case studies would be selected based on classification categories of size of construction firms, construction procurement method, duration of construction projects and so on. Construction cash flow data would be collected at regular intervals during the projects' life for the various categories identified. The data collected for various classification categories would be processed and transformed to develop typologies of construction cash flow models.

### **1.2 Stage 2 (Objective 3)**

In order to construct an expert system model for the management of construction cash flow, an extensive review of existing expert systems addressing construction industry problems would be carried out. Efforts would be made to learn from the strengths and weaknesses of the expert systems, especially those that were developed to manage construction cash flow. Based on this review and utilizing the results of the basic research conducted (objectives 1 and 2), an expert system model will be developed to manage construction cash flow and its associated risks and uncertainties. It is proposed that this model would be in modular form with a module for the knowledge base and another for the database.

### 1.3 Stage 3 (Objectives 4 & 5)

In order to develop a prototype expert system to manage construction cash flow, an attempt would be made at the physical realization of the model constructed under objective 3. In developing the knowledge base module, it is proposed that the knowledge of the domain experts would be captured through structured and unstructured interviews. The knowledge so captured would be kept in the knowledge base module through an appropriate expert system programming language such as Flex, Prolog or C++. It is also proposed that the database to be developed will incorporate the result of the basic research. The prototype would also include a commercial expert system shell, which incorporates an inference engine. The database and knowledge base would be linked to the expert system shell for overall functioning. There would be an input medium for the computer/ human interface and also an output medium.

The developed prototype would be implemented to test its forecasting accuracy by imputing data for proposed construction projects. Where necessary, the system would be de-bugged and re- implemented for satisfactory performance.

### **References**

- Boussabaine, A.H. and Elhag, T. (1999) Applying fuzzy techniques to cash flow analysis. *Construction Management and Economics*, **17**, 745-755.
- Eldin, N. (1989) Cost control systems for PMT use. *Transactions of the AACE*, F3.1 - F3.5.
- Harris, F. and McCaffer, R. (1995) *Modern Construction Management*, Blackwell Science, Oxford.
- Kaka, A.P. and Price, A.D.F. (1993) Modelling standard cost commitment curves for contractors' cash flow forecasting. *Construction Management and Economics*, **11**, 271-283.
- Laufer, A. and Coheca, D. (1990) Factors affecting construction planning outcomes. *Journal of Construction Engineering and Management*, **116**(6), 135-156.
- Lowe, J.G. (1987) Cash flow and the construction client – a theoretical approach, in Lansley, P.R. and Harlow, P.A. (Eds.) *Managing Construction Worldwide*, E & FN Spon, London, volume 1, pp. 327-336.

# TOWARDS PROCESS IMPROVEMENT IN THE FACILITIES SUPPLY CHAIN

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## **Abstract:**

The Structured Process Improvement for Construction Environments – Facilities Management (SPICE FM) project aims to develop a tool for assessing process capability and a framework to distinguish levels of increasing process capability in the facilities management industry. Supply chain management is one of the issues being addressed, and this paper is to present work done so far in understanding issues involved in process improvement in this area. It looks at the methodology and various models and techniques have been applied so far including process modelling and the i2i model, and future models to be considered including the SCOR model and COGENT.

## **Introduction**

The Structured Process Improvement for Construction Environments – Facilities Management (SPICE FM) project is a follow on to the SPICE (Sarshar et al, 2000) project and is funded by the Engineering Physical Sciences Research Council (EPSRC) and the Department of the Environment, Trade and Regions (DETR). The two-year project aims to translate the results of the SPICE project to facilities management as well as integrate this with the Balanced Scorecard model (Kaplan & Norton, 1992, 1993, 1996), the Business Excellence model and the Integrate to Innovate (i2i) model (Barrett & Sexton, 1998), which addresses supply chain management issues, to create a framework for structured process improvement in facilities management.

Supply chain management (SCM) is a borrowed concept from manufacturing, which has recently been highlighted in the construction and facilities industries. A manufacturing based definition of supply chain management is “...all of those activities associated with moving goods from raw-materials stage through to the end user. This includes sourcing and procurement, production scheduling, order processing, inventory management, transportation, warehousing, and customer service” (Quinn, 1997). Other definitions include “.... the explicit creation and systematic management of vital knowledge through the supply chain (Barrett & Sexton, 1998), and “...the management of all the activities in any of the companies involved in a supply chain to achieve two things: **to provide the highest possible level of customer service at minimum cost**” (NITL, 2000).

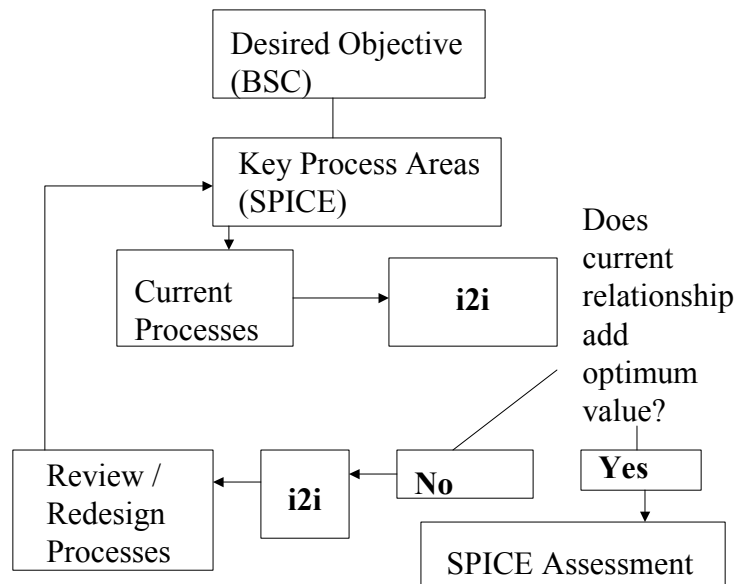
Traditionally, facilities Management (FM) has been seen very simply as the management of buildings and building services. It has been defined variously as “...buildings in use, to the planning, design, and management of occupied buildings and their associated building systems, equipment, and furniture to enable and (one hopes) to enhance the organisation’s ability to meet its business or programmatic objectives” (Becker, 1990), and “An integrated approach to maintaining, improving and adapting the buildings of an organisation in order to create an environment that strongly supports the primary objectives of that organisation” (Barrett, 1995). The US Library of Congress (1989) however defined it as “the development, co-ordination and control of the non-core specialist services necessary for an organisation to successfully achieve its principal objectives”. This definition is more compatible with current thinking in FM that goes beyond the building, and sees FM as the management of non-core functions within an organisation.

## **Methodology**

The methodology for the development of the framework to carry out process improvement in supply chain management in facilities management has evolved over the period of 11 months since the start of the project in October 1999. The three models initially involved in the project are the SPICE, Balanced Scorecard and i2i models. The SPICE model is a five-stage model supported by an assessment framework, which is used to assess an organisation’s management processes. Key process areas in the industry were identified and assessed against five generic process enablers (Sarshar et al, 2000). The i2i model similarly is a five-stage model representing the different levels of relationships within the supply chain. However, unlike the SPICE model in which levels are attained sequentially, the i2i levels can be attained concurrently.

The initial methodology (fig 1) identified the desired objectives of the organisation through the development of a Balanced Scorecard. The SPICE key process areas represented the supply chain relationships assessed. The current processes in the relationships were modelled and the i2i level identified. If the current relationship identified added

optimum value to the organisation, then a SPICE assessment was carried out. If it did not, then the i2i level at which optimum value was added was identified, and the relevant processes reviewed and/or redesigned, before going back through the loop to be assessed.



**Fig 1 (Nelson et al, 2000)**

This was subsequently changed and each model was tested on its own and links drawn between them after the initial pilot case studies. Currently, a series of interviews and literature review are being conducted to determine current thinking in the area of supply chain management within the facilities industry. Other models and concepts including value chain (Porter, 1985), the SCOR model (Stevens, 1998), COGENT (Wyatt et al, 1998) are also been examined to determine their contribution towards managing the facilities supply chain.

### Case Study

The first stage was modelling the business processes of the organisation. Business processes are a sequence of related activities that achieve a value-added business outcome for a customer. This can be broken down into customer focused processes which relate to the core business functions, and enabling processes which relate to the support services such as facilities management, human resource management, financial management etc (Nelson et al, 2000). Modelling is a visual representation of organisation (figs. 2, 3 & 4) that clearly shows not just what they do, but how they do it. It highlighted the fact that roles and responsibilities were not clearly defined, as there were duplications and conflicts within the organisational structure. Workflow diagrams (fig. 5) were also used to highlight communication gaps in service delivery.

The second stage was testing the i2i model. The assessment test was a quick and good way of determining the current and the desired levels of the supply chain relationships. It highlighted the areas of priority where there is disparity between the current and desired levels. This was then measured against how strategic the relationship was in order to prioritise areas for improvement.

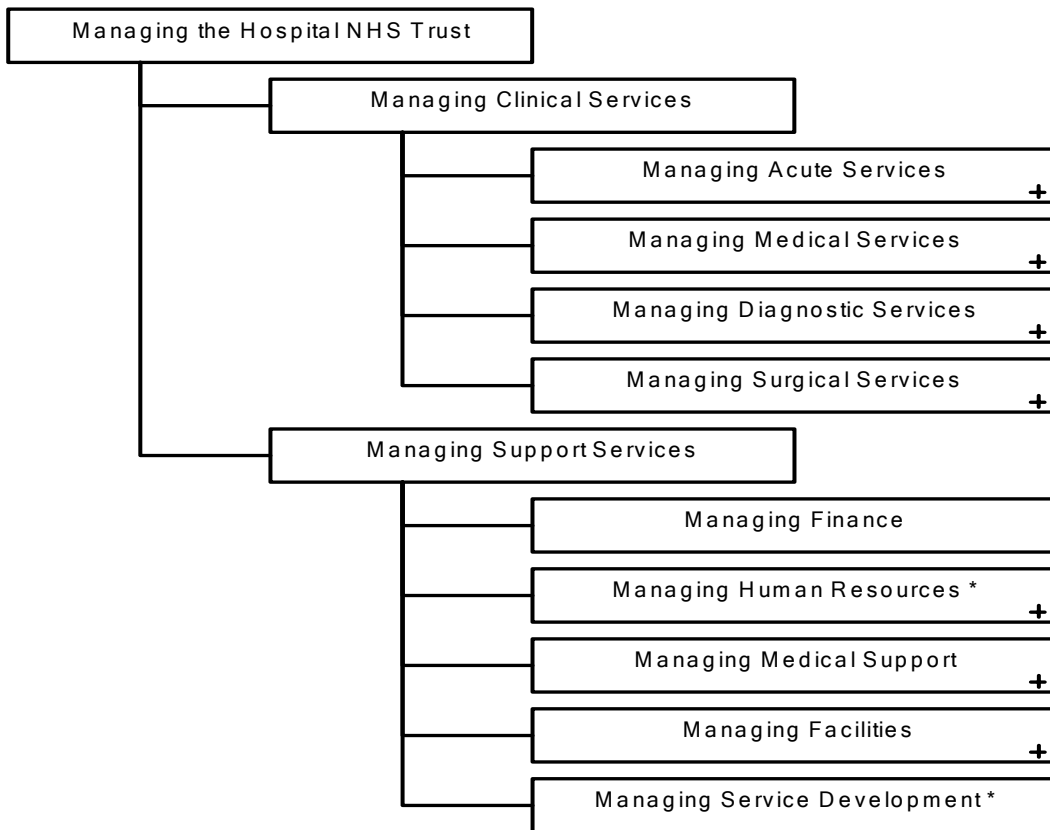


Fig. 2 (Nelson et al, 2000)

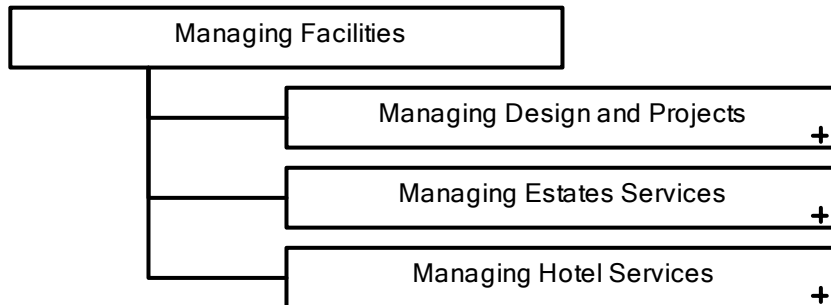


Fig. 3 (Nelson et al, 2000)

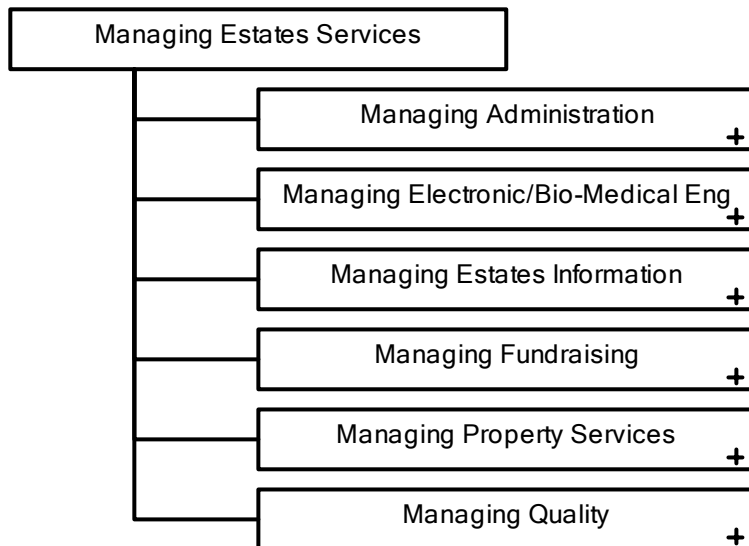


Fig. 4 (Nelson et al, 2000)

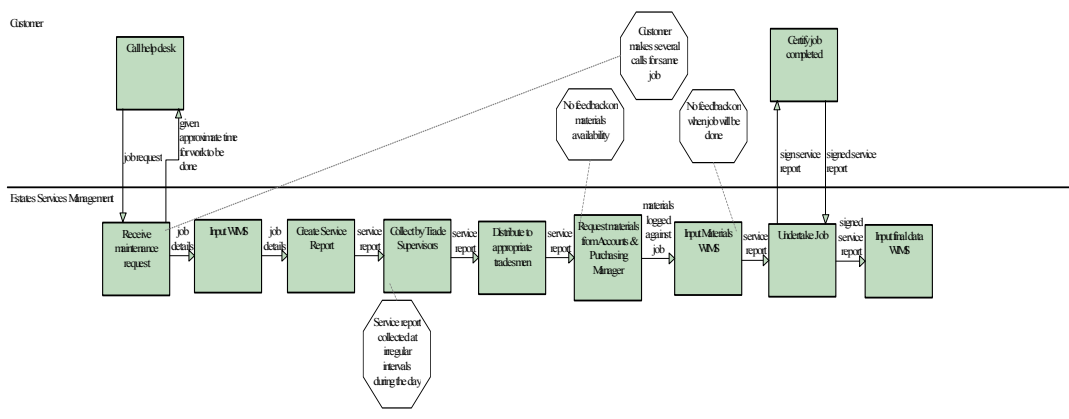


Fig. 5 (Nelson et al, 2000)

### Current work

A series of interviews are currently being conducted with leading experts in this industry. Both clients and service providers are represented amongst interviewees. At the moment no consensus has been found amongst industry practitioners on what the most important issues are. As the concept is newly emerging and the provision of facilities services is currently evolving, the industry is still undecided about which issues to highlight. The applicability to facilities management of the SCOR model and COGENT concept which have been applied in supply chain management in the manufacturing and automotive industries respectively are also been examined. The results of this will determine the direction of future research in this area.

### Conclusion

Process modelling can be used on its own as a process improvement tool, but it is an even more powerful tool when used in conjunction with other techniques. The i2i model has been seen to highlight areas for a GAP analysis to be carried out. Supply chain management is seen to be a very important issue in facilities management as it is involved in service delivery involving a complex supply chain. The concept therefore covers a vast and complex area of study. Developing a framework for process improvement in this area is therefore challenging and requires an in-depth study of not just current thinking in this area, but the future direction of the facilities industry.



## References

- Barrett, P., 1995. *Facilities Management – Towards Best Practice*. Oxford: Blackwell Science.
- Barrett, P. & M. Sexton, 1998. *Integrating to Innovate – Report for the Construction Industry Council*.
- Becker, F., 1990. *The Total Workplace: Facilities Management and the Elastic Organisation*. New York: Van Nostrand Reinhold.
- Kaplan, R. S. and Norton, D.P., 1992, “Balanced Scorecard: Measures That Drive Performance”, *Harvard Business Review Article*, 1992, January.
- Kaplan, R. S. and Norton, D.P., 1993, "Putting the Balanced Scorecard to Work", *Harvard Business Review Article*, 1993, September.
- Kaplan, R. S. and Norton, D.P., 1996, "*The Balanced Scorecard; Translating Strategy Into Action*", Harvard Business School Press, 1996.
- Nelson, M., Sarshar, M. And Stokes, E., 2000. Process Improvement In Facilities Management Using The Spice Approach. In Faraj, I. And Amor, R., (Eds.), 2000. *Proceedings Of UK National Conference On Objects And Integration For Architecture, Engineering And Construction*. Watford: BRE. 13 – 14 March.
- NITL, 2000. *European driving Licence in Supply Chain Management<sup>TM</sup>*.
- Porter, M.E., 1985. *Competitive Advantage – Creating and Sustaining Superior Performance*. New York: The Free Press.
- Quinn, F.J., 1997. “What’s the buzz?” *Logistics Management*. Pp 1.
- Sarshar, M., M. Finnemore, and R. Haigh, 2000. *Introduction to SPICE*, Construct I.T.
- Stephens, S., 1998. *Supply Chain Council & Supply Chain Operations Reference (SCOR) Model Overview*. Keynote presentation at the 1999 supply chain world conference and exposition, Amsterdam.
- US Library of Congress, 1989. In Mole, T. and Taylor, F. (1992). *Facility Management: Evolution or Revolution*. In Barrett, P. (Ed.), 1993. *Facilities Management – Research Directions*, London: Surveyors Holdings Limited.
- Wyatt, C. M., Evans, S., and Foxley, K., 1998. “The integration of vehicle manufacturers and their suppliers prior to product development”. *Design Re-Use*. Professional Engineering Publishing. Pp. 613-620.