A fuzzy logic decision support system for routing materials on construction sites

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ABSTRACT | The ability to accurately plan and visualise routes for materials movement on complex construction sites is a major determinate of project success (or conversely failure). However, materials routing design complexity and the bespoke nature of individual projects places a unique burden upon project planners and site managers. This paper presents a software tool, called Virtual Construction Material Router (VCMR) that can generate materials routing scenarios sequences based on: i) site layout; ii) delivery routes; iii) construction activity schedules; and iv) temporary accommodation location. The heart of the VCMR is a Geographic Information System (GIS), fuzzy logic based decision-support system, which enables planners to determine the most appropriate route for material deployment. The system also has the inherent ability to enable planners to select and visualise the most suitable material movement routes. Validity of the developed VCMR system was achieved by observing model accuracy when employed on two complex construction sites.

KEYWORDS | materials route, decision support systems, visualisation, fuzzy logic, GIS

1 Introduction

Materials routing on construction sites is heavily reliant upon the experience and intuition of site managers and planners (Yang and Mahdjoubi, 1999 and 2000). Unfortunately, the changing characteristics of the construction industry workforce has created a skills shortage in this specific knowledge domain (Winch, 1999). This problem is further exacerbated by the fact that younger site managers and project planners are unable to benefit from the experience and intrinsic knowledge of complex site operations retained by retiring predecessors (Winch, 1999).

Planning of access and routing for materials on construction sites is therefore of quintessential importance to the effective and efficient progression of projects. An emerging body of research suggests that ineffectual materials routing on site is one of the main causes for cost and time overrun (Muehlhausen 1991, O'Cornor, 1995). Further, when considering material movement costs, estimates reveal that 30–80 percent of each projects' total construction cost are attributed to such activities (McCullouch and Gunn, 1993). Therefore, mismanagement of materials routing could exert serious financial implications on the final project outcome and wield significant consequential damage

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upon the contractor's profitability. In addition, the demand for increased shareholder value and enhanced project profit margins has stimulated the need for a tool(s) that will support site managers and planners when formulating decisions regards materials routing and storage locations on construction sites. This paper describes the development of the Virtual Contraction Materials Router (VCMR) software package, which has the ability to assist site managers and planners in dealing with materials movement problems.

2 Historical Developments and Innovations

Considerable attention has been paid to materials management functions in recent years. Bell and Stukhart (1986) for example, suggested that such functions could be defined as:

"material requirement planning and material take off, vendor evaluation and selection, purchasing, expenditure, shipping, material receiving, warehousing and inventory, and material distribution."

Throughout Bell and Stukhart's research it was emphasised that material management systems as a discipline, are concerned primarily with the effective planning and controlling of all necessary materials and equipment. It was further determined that materials and equipment demands should be modelled accurately to ensure that the right quality and quantity of materials were installed and that the appropriate equipment is specified in: i) a timely manner; and ii) at a reasonable cost

Hazem and Bell (1995) took Bell and Stukhart's work a stage further and suggested that project materials management systems should be integrated into an appropriate computer systems which could design and schedule the project. The Object Oriented Methodology (OOM) data structure was proposed to be the most appropriate method to develop an efficient and effective materials management system. OOM is defined as the holistic management of materials from initial sourcing to final fixing. Hazem and Bell's proposition was reinforced via the work by McCullouch and Gunn (1993) who developed a computer-based material management system. This software was claimed to save 26 to 37 percent of a field supervisor's time, over and above 'normal' uncomputerised materials management systems that could be employed. Evidently, this work indicates that computerisation can reduce management time and subsequently decrease associated materials management paper work.

More recent concepts introduced and utilised in the materials management domain include the combination of a Decision Support System (DSS) with knowledge-based systems, artificial neural network and fuzzy systems (Feng and Xu, 1999). Decision support systems (DSS) are defined as interactive computer-based systems, which can help decision-makers utilise data and model it to solve unstructured problems (Robbins, 1991). The research by Feng and Xu (1999) developed an integrated system in which a knowledge based decision system, artificial neural network and fuzzy system were combined in a hybrid knowledge management decision making system for use in the urban design process. Hanna and Lotfallah (1995) used a fuzzy logic approach to select the most suitable crane type for any particular construction project. It was emphasised that because fuzzy logic emulates human decision making (when embracing such a procedure in materials management) the recommended outcomes of the system more accurately reflect real life solutions.

In recent years, the neuro-fuzzy hybrid approach has dominated research in computerised construction management. Yu and Skibniewski (1999a) developed a multi-criterion neuro-fuzzy knowledge decision model for quantitative constructability analysis. It was suggested that project management could be quantified, measured and improved by using the software package. Further, the palpable advantage

of neuro-fuzzy knowledge lies in its intrinsic ability to be used as a mechanism through which to trace back factors that negatively influenced construction performance. By observing these negative factors, feedback to construction engineers can be made. Whilst not a panacea to poor performance problems, such feedback does allow managers to adequately assess given problematic situations and attempt to resolve them.

Shaked and Warszawsk (1995) created a knowledge-based system for construction planning. This system was designed as an automatic planning system for aiding managerial decision-making. The system's objective was to operate at least cost, increase managerial efficiency and speed project completion. Boussabaine and Duff (1996) developed a knowledge-based and neural network system that could be used for construction productivity forecasting. It was hypothesised that the knowledge-based and neural network system could deal better with uncertainty that is naturally present in decision-making processes.

Finally, a strong interest has emerged in the field real-time simulation and rehearsing applied to construction processes (Ribarsky, et al, 1994). Rehearsing in this research uses simulation software to represent the final 'decision' graphically. Researchers at Georgia Institute of Technology developed an Interactive Visualiser allowing the exploration of geometric primitives and operations on a virtual construction site. Preliminary results would suggest that the approach used could make a significant impact upon construction project information supplied.

3 Decision Support Systems (DSS) and Materials Routing: Previous and Proposed Developments

The principal objective of DSS is to support managerial decision-makers in a semi-structured decision situation. A semi-structured problem is typically represented by problems that exist but do not have any specific plan. For example, due to inclement weather conditions, a programme of works may change where wet trades (that is, bricklayers, concreters etc.) would have to change activities without prior notice; this may involve working undercover on other programme tasks (Keen and Scott-Morton, 1978). These systems are designed to extend the capabilities of decision-makers as opposed to totally replace their judgement. Because of this functionality, DSS is arguably the most suitable method available to deal with materials movement route selection. Turban (1993) reported that a DSS is an interactive, flexible and adaptive Computer-Based Information System (CBIS), which can be developed to provide improved decision making to support a particular management problem. A CBIS system is therefore used to assimilate a quantity of data and prescribe the most appropriate action to be taken.

Varghese et al.'s (1995) work is accredited as being the pioneer of DSS applied to materials routing problems. Specifically, the system developed optimum routing solutions for large vehicles on construction sites. Using proprietary Computer Aided Design (CAD) software, Geographical Information Systems (GIS) and spreadsheet software, a system was developed to interlink with other custom built programs to evaluate large vehicles access scenarios on the project site. Varghese et al. (1995) determined that:

"access considerations have a strong influence on the layout of temporary facilities, location of assembly and storage yards, layout of roads, construction sequence, extent of assembly, and design of overhead and underground elements crossing the roads."

This is an important observation for the development of any routing system because materials movement is a key consideration in project planning. Specifically, materials routing is known to influence the physical location of materials storage locations. This is because unnecessary materials re-handling and additional transportation incur additional costs onto the project budget.

Because of the aforementioned observations, a series of tools have been subsequently developed to aid materials handling and site layout control and thus reduce materials re-handling costs. Specifically, MoveSchedule was designed as a planning tool for scheduling space use on construction sites. The system was capable of modelling and hence, recommending a site layout for materials storage locations based on site space usage; with the objective being to minimise resource transportation and relocation costs (Zouein, 1996). Another software package, MovePlan was developed to assist planners and managers create sequences of layouts corresponding to developed project activity schedules. This system principally informed suppliers about material unloading locations and workers about material storage on construction sites (Tommelein, 1994).

Despite these developments, little research has been conducted to deal with the specific topic of materials 'routing' on construction sites. Yet clearly, there is a need for tools that will empower site managers and planner's with proficient decision-making capabilities with which to resolve complex materials routing and storage location problems. From the literature review it was apparent that the development of a dedicated DSS for routing decisions would provide a pragmatic and useful solution. Hence, the rationale to create a Virtual Construction Material Router (VCMR) for planning, executing, and controlling of routing of materials.

4 Requirements of VCMR: Model Development

To determine appropriate materials routing directions for complex construction projects a novel analysis technique was employed. Specially, spatial data was processed using a fuzzy logic system and the results graphically displayed in a visualisation system. The combined power of these aforementioned processes and data observations aids the selection of the best scenario for materials routing decisions. However, during tool development, several features were deemed to be important considerations of the VCMR, namely:

- Generate scenarios. This process involved generating essential data such as site coordinates and attributes that have an impact on materials routing decision-making. The generate scenarios process is therefore critical to the decision making processing because of: i) the demand for both processing the informational content of the input data set (building position, storage locations etc.); and ii) the ability to extend links back into the database where the original data is stored.

- Task driven. The task driven system was developed primarily to deal with specific material routing tasks on complex construction sites. As a generic function, the task driven system takes into consideration factors such as site layout, scheduling and sequence of construction and temporary location of materials; all of which may affect route selection.

- Visualisation. Visualisation represents the final results of the generated scenarios. It is based upon careful consideration of both task driven factors as well as integrating user software input variables. Specifically, work involved the generation of a spatial database, which includes data set linkages identification for spatial analysis. The results were graphically represented using the querying function combined with the GIS software.

- User-friendly. Utilisation of Visual Basic language allows a user-friendly interface to be developed and enables users to communicate efficiently with the software (that is, with reference to route selection, criteria of route and transfer selected). Resultantly, data processed could indicate the final/recommended material movement route.

5 System Architecture

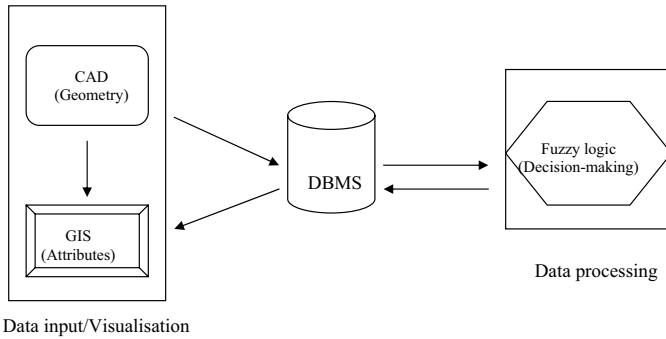Based on the above activities, the structure of VCMR was constructed as shown in Figure 1.
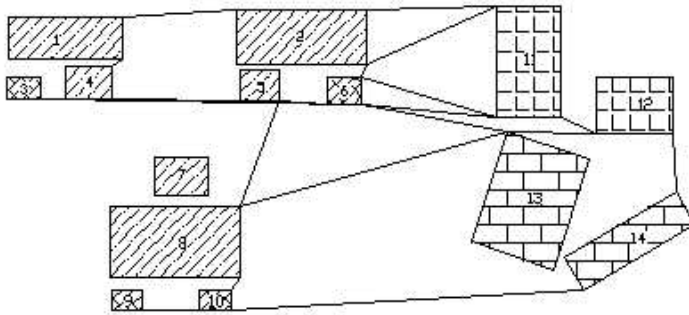
Figure 1. Structure of VCMR

Figure 2. A completed site layout

The geometry of the site layout was created using a CAD package (i.e. AutoCAD). Relevant site information (for example, the location of new buildings, access onto the site, temporary and permanent facilities, impediments, storage areas, compound areas, entrance and exits etc.) was an essential component of site layout schematics that enabled a more detailed geometry to be determined. Geometry is a prerequisite part of data collation because is facilitates processing of input routing criteria required to make the final decision of materials movement. Spatial relationships between site features and attributes are determined using GIS (i.e. AutoCAD MAP). Figure 2 illustrates an example of the site layout used for this research. This information was used to develop the fuzzy model and spatial attributes that are needed to determine possible routes between different locations on the site.

Site geometry and spatial attributes are subsequently stored in a database management system (i.e. MS Access) in a text format (this is completed using GIS functions). As work on site progressed, thematic data relating to site spatial attributes was revised and updated through a user interface (Figure 3). This updated information was then stored in the DMBS. Information stored in a DBMS is held in a text format and is therefore ready for visualisation and presentation to the planner. Additional information can be retrieved by executing the query function in AutoCAD MAP. This graphical representation enables site managers
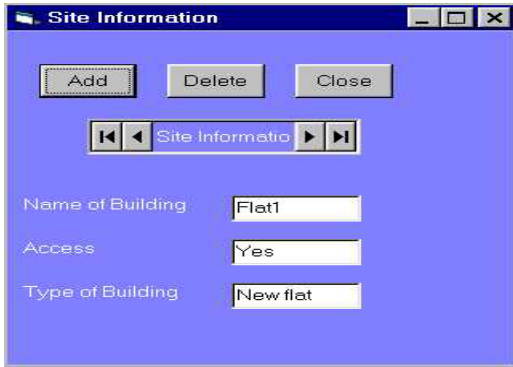
Figure 3. DBMS in VCMR

and planners to identify possible conflicts of material movement and activities. It also allows the rehearsal of various scenarios for different construction activities to be delayed or advanced.

6 VCMR Development: An Appraisal of Results

Using the aforementioned criteria, a prototype of VCMR intelligent routing selection system was developed. The routes were produced by the decision-making system (Figure 4), which use a rules based fuzzy logic system to process the input criteria of routing. A rules based detail approach relied on fuzzy set theory to deal with uncertainly in material management reasoning. This spatial data allowed the fuzzy logic system to automate data processing and resultantly, graphically display appropriate material routes for each project. Computerised and automated outcomes will invariably help in the selection of the best routing decision by effectively reducing computational time.

At this stage in the software development, the study also explored linking the decision making results to a real-time visualiser. It was envisaged that a fuzzy logic system (FuzzyTECH) could be employed for this process as an independent decision making process. FuzzyTECH incorporates a function that allows each site's unique characteristics to be embraced; hence, the developed programme has the capacity to represent real life scenarios. The fuzzy logic system was designed based on 'If…Then' rules to generate decisions. The factors (e.g. building location, storage areas) were catalogued and divided into different hierarchies in the decision design procedures. The top-level variables were those that needed knowledge regards material termination points on site, that is, where the materials were going to be used. This means that the final destination of materials was (logically) the most important variable. Because of the importance of this observation, various terms were collated for each and every material to be used on the project. For example, name of destination, date of materials needed, time of materials needed and type of material (e.g. brick, concrete, windows, and doors etc.).

Software user defined criteria for any material could also be selected or entered through the VCMR. This process allowed the interface to supply further analytical queries (for example, date and time and materials requirement); where the later includes the destination of materials, the types of materials, the date and time, and the materials storage locations (Figure 5). Figure 5 illustrates the user interface through which user can enter and select materials routing criteria.

Figures 6 and 7 illustrate a visualisation created by the VCMR based on the criteria-set output for complex construction sites. After routing selection, users can display the routing of materials using the CAD/GIS package. All relevant data obtained from the site attributes and site geometry information are stored in a new table within the existing database. Users can also run SQL query in AutoCAD Map and display the final decision in graphical format. This graphical representation will enable site managers to identify possible conflicts of material movement and activities; it also allows the rehearsal of various operational scenarios.
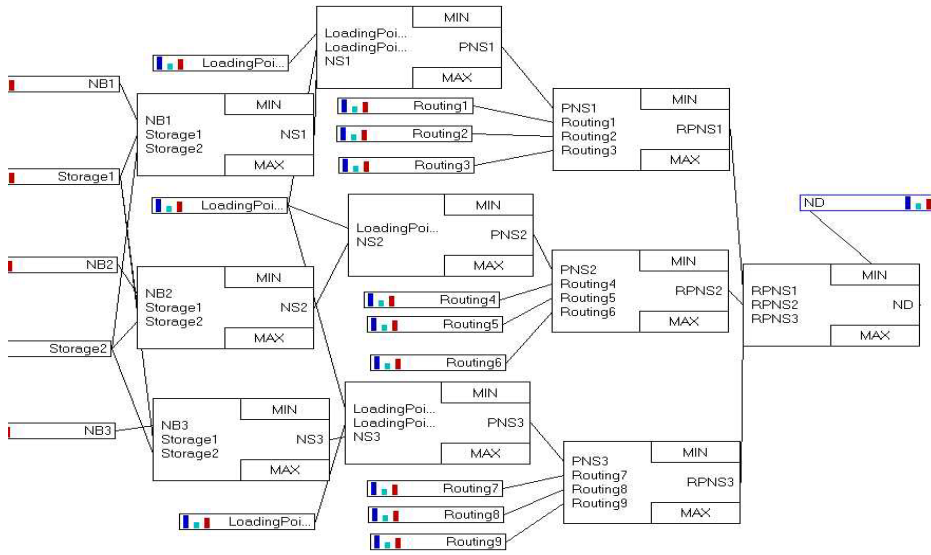
Figure 4. Fuzzy logic decision-making systems in VCMR

7 An Applied Example-Application of VCMR

Validity of the software was achieved through the use of case study. For this purpose, the Royal Navy's Vanguard number 9 Dock at Davenports Royal Dockyard, Plymouth was used. The dock was being constructed by Carillion Plc and was intended to be used for docking nuclear submarines. The project was valued at £60M (UK sterling) and was planned to be completed in 33 months (November 1998 to August 2001).

The main physical attributes of the construction site were that it was long and thin; specifically, the site was 320m long and 50m wide. Because of this trait, correct materials routing and access were key to the project's success. The site was composed of three docks, Dock 8, 9, and 10. The dimensions of the No.9 dock are approximately 250 in length, 32m in width and 12m in depth. Dock 8 and 10 are important to consider in the construction of Dock 9 because Docks 8 and 10 are physically close

to Dock 9 and unrestricted access was required to these docks during construction works. Hence, there are physical materials routing restrictions were imposed on Dock 9 by Docks 8 and 10.

7.1 Characteristics of the site

Two types of materials were mainly required for the project; these being 15,500 tonnes of steel and 90,000 m^3 of ready mixed concrete for whole project. Three deliveries were planned for the 8th August; these deliveries being staggered to arrive at dock No.9 at 06: 50, 15:00 and 18:00 (Table 1). Scheduled tasks in the same day included fixing reinforcement in the East dock wall and filling the existing chamber with concrete. To predict the route for concrete deliveries movement on site, the following information was required.

- Type of materials: Concrete, Reinforcement, Wood-frames, Casting Items. The developed VCMR includes a list of materials which are used in most construction projects. The user can therefore select the suitable type of materials as required.
- Destination of materials: Dock foundation

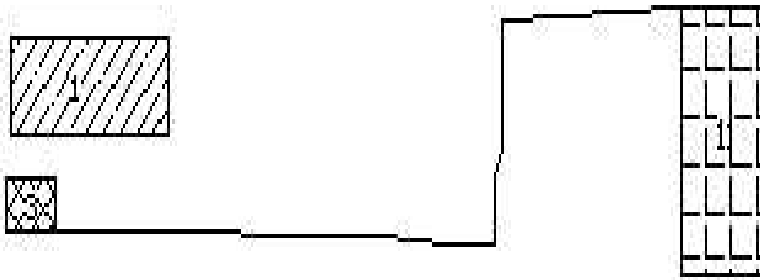**Figure 5.** Selection and entry criteria in VCMR
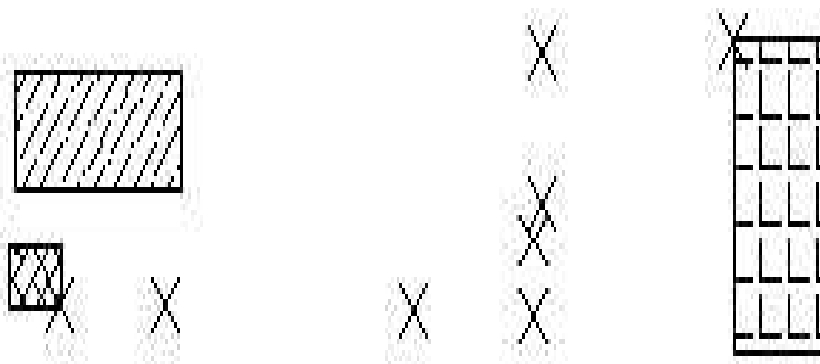

Figure 6. Related nodes of routes

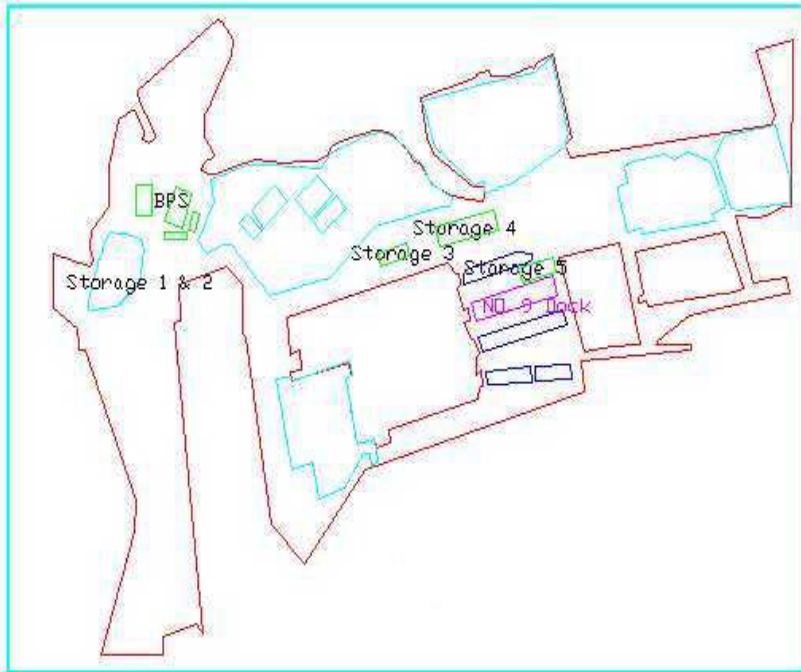

Figure 7. Route for material movement
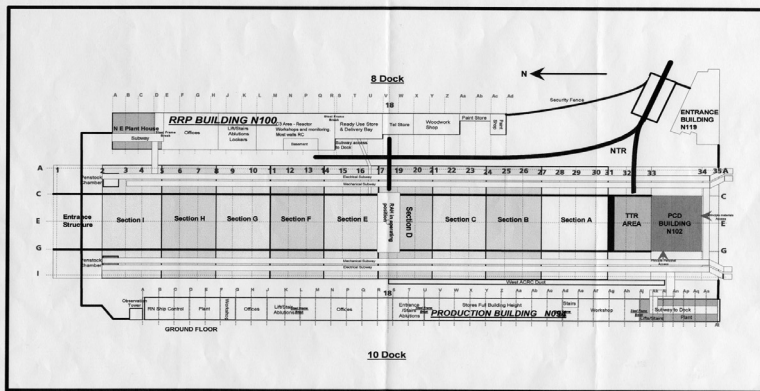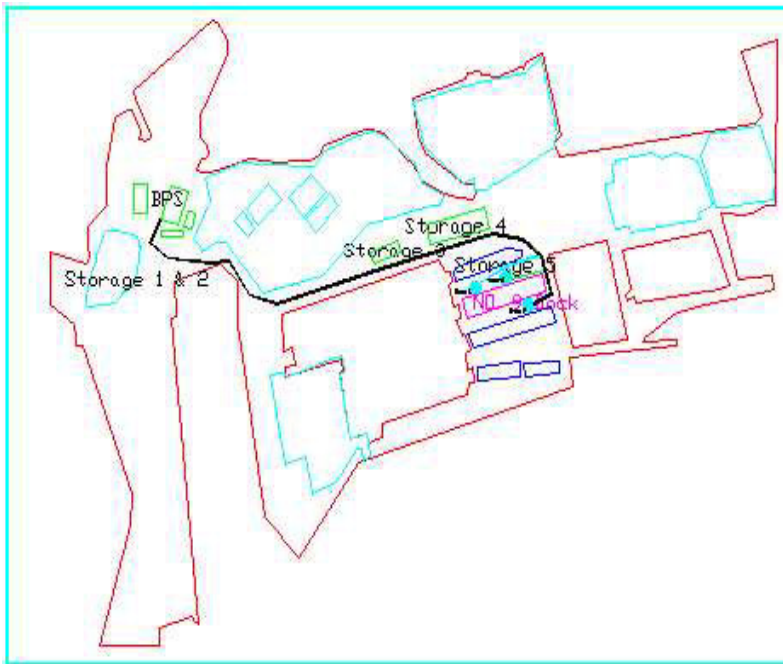
Figure 8. Site layout

Figure 9. Layout of dock No. 9

Figure 10. Route selected for concrete by VCMR

- Temporary Storage of materials: West Mile1, West Mile2, Compounding, Workshop, and Temporary storage, Batching Plant Station (BPS), Trail Area.
- Offloading position of materials and equipment: Crane 1, Crane 2, Crane 3 and others.

There was a special arrangement made between the concrete manager and concrete supplier, such that the concrete supplier would be informed one day in advance of any delivery requirements. Concrete deliveries were then confirmed to the concrete manager prior to delivery. The concrete was ordered on the 7th August (390m³ was required) and the batching plant station (mixing concrete) was duly informed and details regarding concrete specification forwarded. On the 8th August, the material was ready for delivery.

8 Validation Procedure

An experienced project manager, working for Carillion Ltd utilised the VCMR software to carry out the validation of the programme. The manager was informed of the underlying rationale for the software development and was keen to be involved in the validation procedure.

Prior to physically attending site, paper copies of the site plan and detailed explanation of the project schedules and materials requirement were received. Two operational phases were used. The first phase involved site layout design and the generation of route networks. AutoCAD was used to input the site layout into the VCMR. Data which was included in the digital layout were the materials' destination (No.9 Dock), temporary storage areas, plant position (cranes), and batching plants. AutoCAD Map was subsequently used for attaching site attributes and analysing spatial data (e.g. Dock name, location of cranes).

Once the relevant information was loaded onto the VCMR software, the second phase used the VCMR

Table 1 Concrete order form (Project D154, Carillion)

to generate the most suitable scenario for materials routing between storage areas and offloading locations. A typical scenario of materials routing was selected to test the software. This involved the delivery of mixed concrete to Dock No. 9. This validation test was carried out using the project manager's experience and knowledge. Essentially, the project manager was asked to assess practicality of the routes selected by VCMR and compare these to those routes generated by project mangers.

8.1 Preliminary result

The routes generated by the VCMR were compared to those suggested by project managers. The result of the analysis carried out by VCMR are illustrated in Figures 8 and 9. The system suggested that the materials needed to be routed from the concrete station along storage positions 3, 4 and 5 and Dock 8 and 10 to its offloading position (crane 1, 2 and 3). This result took into consideration the site layout, project schedules and site route networks and temporary obstructions.

However, it should be noted that some discrepancy was apparent between the VCMR route and the project manager's preferred route. This was due to unforeseen circumstances, namely the temporary entrance to Crane 3, and Crane 2 was obstructed which prevented material movement along this route. This was not predicted by the VCMR because the project manager wanted to carry out 'other' construction activities at these key locations and this information was not transmitted to the software. Second, the distance between dock No.8 – 9 and No.9 – 10 was too narrow to enable the routing of large vehicles. The lesson here is that one cannot legislate for human error regardless of the accuracy and complexity of the software system developed. In turn, this exercise would suggest that an applications manual or similar instructional literature (augmented with taught introductory software tuition) should accompany future editions of the software.

9 Conclusion

Accurate and effective materials movement and routing on construction sites is a prerequisite if a project is to succeed on both time and cost frontiers. Despite this inevitable observation, materials' planning has received minimal attention to date.

This lack of cohesive work is further exacerbated by the fact that those planners who possess sufficient knowledge and skills are predominantly eligible for retirement. Resultantly, inexperienced planners are expected to replenish the industry and take on project planning without having necessarily served a suitable apprenticeship.

To aid this situation, a GIS fuzzy logic based software tool has been developed to aid materials planners in determining the most appropriate routes and storage space for materials. Using the software detailed in this paper, planners are able to simulate and model a plethora of materials routing options and identify the optimum route of materials transportation. The developed software has the ability to take into consideration site layout geometry and project plan and sequence such into an order that can be physically followed by site works progress. In all, the software has an ability to aid planners in their decision-making roles and further offer them a set of options to ensure that materials are delivered at an appropriate time and in the correct quantity.

The effectiveness of the derived model was determined by its utilisation on a complex construction site; namely, the construction of Dock 9 at Plymouth which will be used to house nuclear submarines. Because the software development is in its infancy, further user-friendly functions and modifications will be required. Regardless of model accuracy, it does not currently account for missing data and operator error. Despite this, the fuzzy logic based system has exhibited an inherent ability to model complex construction sites materials routing conundrums.

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