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DECISION SUPPORT SYSTEM FOR OPTIMIZING CONSTRUCTION SITE LAYOUTS

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ABSTRACT

Construction site layout planning requires decision makers to identify the planned location of each temporary construction facility on site. These temporary facilities include site offices, workshops and storage facilities; and their planned locations on site have a direct impact on the safety and efficiency of construction operations. As such, construction decision makers need to carefully evaluate all feasible locations for these temporary facilities and select an optimal layout that maximizes safety and efficiency of construction operations. This paper presents the development of an automated DSS that is designed to support construction planners in this multi-objective site layout optimization problem. The system incorporates four newly developed modules: (1) a multi-objective optimization module to quantify and optimize the impact of site layout planning on construction safety, and the travel cost of resources on site; (2) a relational database module to facilitate the storage and retrieval of construction site layout data and the generated optimization results; (3) a user interface module to facilitate the input of project data and the analysis of the generated optimal site layout plans; and (4) a visualization module that interfaces with external CAD software to support the visualization of optimal site layout plans. An application example is analyzed to illustrate the use of the system and demonstrate its capability in generating optimal trade-off plans between construction operations safety and efficiency.

KEY WORDS

optimization, construction sites, evolutionary computation, safety, decision making.

INTRODUCTION

Site layout planning requires decision makers to specify the location of each temporary construction facility on site in order to achieve a number of objectives including: (1) minimizing the travel time and cost of resources; and (2) improving the safety of construction operations (Tommelein et al. 1992; Anumba and Bishop 1997; El-Rayes and Khalafallah 2005). A number of methodologies have been adopted in the literature in order to develop site layout planning models. These methodologies included linear programming (e.g. Armour and Buffa 1963, Dawood and Marasini 1999), genetic algorithms (e.g. Tam 1992, Li and Love 1998, Hegazy and Elbeltagi 1999, Mawdesley et. al. 2002), knowledge-based systems (e.g. Kumara et al. 1988, Hamiani 1989, Tommelein et. al. 1991, Tommelein and Zouein

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1993), artificial neural networks (e.g. Yeh 1995), and simulation (e.g. Dawood and Marasini 2001, Tawfik and Fernando 2001). Despite the contributions of these models, they adopted only the objective of minimizing the travel cost of resources on site as the main criterion in designing site layout plans. There is little or no reported research studies that considered construction safety as an independent optimization objective despite its importance in the construction industry which suffers form a very high rate of accidents on site. For example, the construction industry is ranked as the first in causing nonfatal injuries with a rate of 9.3 injuries per 100-full time workers (NIOSH 2000); and among the top three industries in causing fatal injuries in the United States with a rate of 12.2 fatalities per 100,000 workers (BLS 2004). As such, there is a need for practical and automated systems for the optimization of site layouts that account for and improve the safety of construction operations while simultaneously minimizing the travel cost of resources. This paper presents the development of a multi-objective decision support system for optimizing construction site layouts that addresses this need, as shown in Figure 1.

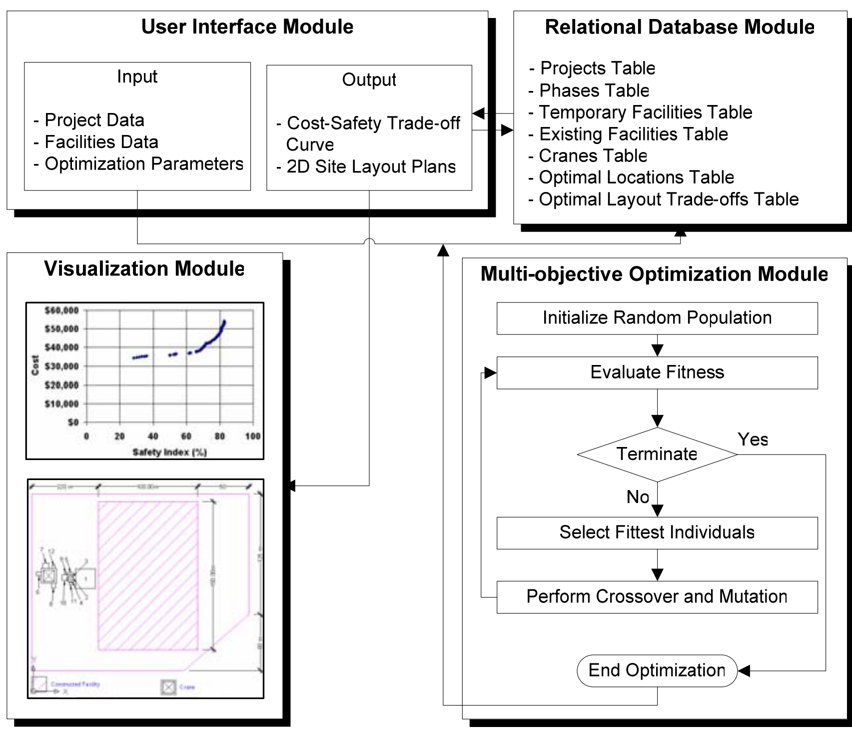

Figure 1: Main Modules of the Decision Support System

The main objective of the present system is to provide practical automated support for construction planners who need to optimize the design of site layout plans. To this end, the present system is designed to provide a number of unique and practical capabilities, including: (1) utilizing multi-objective genetic algorithms in order to enable simultaneous optimization of construction operations safety and travel cost of resources; (2) automating the development of trade-off charts between construction operations safety and travel cost of resources on site in order to facilitate the evaluation and selection of optimal site layout plans; and (3) supporting the visualization of site layout plans through integrating the system with available CAD software. To provide the aforementioned capabilities, the present system is developed in four main modules: (1) a multi-objective optimization module to quantify and optimize the impact of site layout planning on construction safety, and the travel cost of resources on site; (2) a relational database module to facilitate the storage and retrieval of construction site layout data and the generated optimization results; (3) a user interface module to facilitate the input of project data and the analysis of the generated optimal site layout plans; and (4) a visualization module that interfaces with external CAD software to support the visualization of optimal site layout plans, as shown in Figure 1. These four modules are described in more detail in the following sections.

MULTI-OBJECTIVE OPTIMIZATION MODULE

The main function of the multi-objective optimization module is to perform a series of genetic algorithm operations in order to simultaneously maximize construction safety and minimize the travel cost of resources on site. These genetic algorithm operations are repeated to generate better and better solutions until the generated solutions evolve to a stable state. As shown in Figure 1, these operations start with generating a set of random candidate site layout solutions. From this set of candidate solutions, new solutions are reproduced, through a number of genetic algorithm operations such as crossover and random mutation, forming an offspring population. The population is then evaluated to select best candidates to undergo crossover and mutation again in an iterative process that seeks to eliminate the worst candidate site layout solutions and keep the best ones. The selection of individuals here is based on the domination and ranking criterion (Deb et al. 2000). In selecting the best candidates, each candidate site layout solution is evaluated based on two criteria: (1) the overall construction safety (El-Rayes and Khalafallah 2005); and (2) the total travel cost of resources on site. First, the overall construction safety criteria is designed to improve the safety of crane operations by selecting safe locations for temporary facilities around cranes; control hazardous material on site by providing adequate separation between combinations of facilities that can create hazardous conditions; and reduce intersections between heavily traveled routes of resources to minimize the potential of accidents and collisions that can occur in these points. Second, the total travel cost of resources can be optimized by minimizing the travel distances of resources among construction facilities on site.

RELATIONAL DATABASE MODULE

The main function of this module is to develop a relational database in order to store the necessary site layout input data (e.g. temporary facilities attributes, existing facilities attributes, crane data …etc.) and the generated optimal site layout data. This module is composed of seven main tables that are designed to store the following site layout planning data: (1) project information; (2) project phases information; (3) temporary facilities attributes; (4) existing facilities attributes; (5) crane data; (6) optimal locations of temporary facilities; and (7) optimal trade-offs between objectives. Figure 2 illustrates an entity relationship diagram that describes the attributes of these tables and the relationships among them using a crow’s foot model (Rob and Coronel 2002).

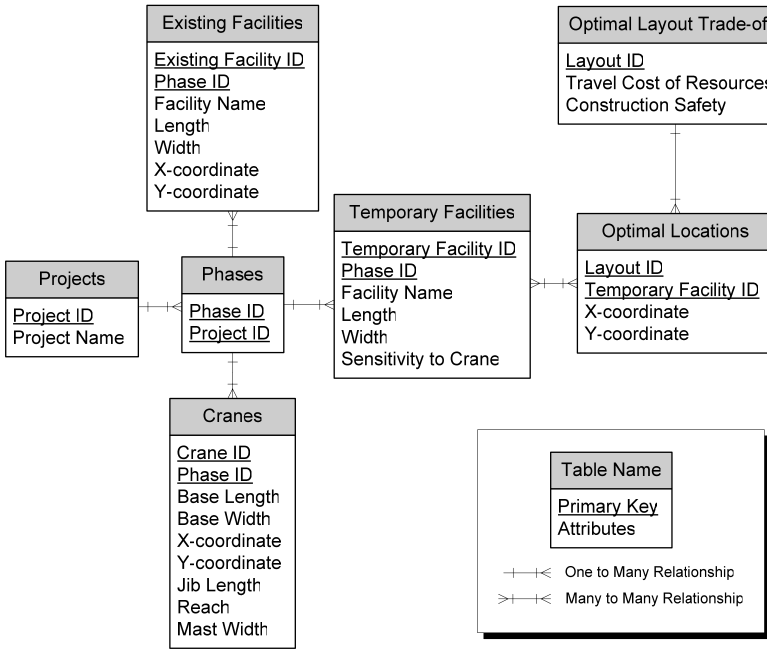

Figure 2: Entity Relationship Diagram

The "Projects" table is designed to store information about the project being planned such as its name and ID. This table is linked to the "Phases" table using a one-to-many relationship. The "Phases" table stores information on the various time-dependant phases of each project to facilitate the evolution of dynamic site layout planning in construction projects. The "Phases" table is also linked using a one-to-many relationship to (a) the "Temporary Facilities" table which stores the ID, phase ID, name, length, width, and sensitivity to crane information of each temporary facility that needs to be assigned a location on site; (b) the "Existing Facilities" table that stores the locations, dimensions, and information about the facilities which are already exiting on site; and (c) the "Cranes" table which stores the information about each crane utilized on site such as its base length, base width, jib length, reach and mast width. The "Temporary Facilities" table is linked to the "Optimal Locations" table which stores the generated optimal locations for each temporary facility using a many-to-many relationship, as shown in Figure 2. The "Optimal Layout Trade-offs" table is designed to store the travel cost of resources and the construction safety index of each of the generated optimal site layout plans; and is connected to the "Optimal Locations" table using a one-to-many relationship. The data stored in these tables is entered by the user through a graphical user interface in an organized procedural process.

USER INTERFACE MODULE

The user interface module is developed to facilitate the input of all necessary site layout planning data and the output of generated optimal site layout designs. This module is designed to implement its functions in two main phases: (1) an input phase to store construction site data, temporary facilities attributes, and genetic algorithm parameters; and (2) an output phase to facilitate the retrieval of the optimal site layout plans from the system database in order to visualize them in CAD software environment. The module is implemented using Microsoft Visual Basic to benefit from its advanced capabilities in facilitating the development of graphical user-friendly interfaces and the integration of all the DSS modules. The relationships and interactions between the input and output phases in the present module and the other modules of the DSS are illustrated in Figure 1. The following two sections discuss the flow of data during the input and output phases in more detail.

INPUT PHASE

The input phase is designed to help the construction planner enter and store all the necessary planning and optimization data needed to optimize the site layout plan. During this phase, the user is asked to enter planning data about (1) existing facilities on site; (2) temporary facilities that are planned to be used on site during construction operations; and (3) cranes, if any, as shown in Figure 3. The input phase also facilitates the input of the genetic algorithm parameters which are needed to run the multi-objective optimization module. These parameters include: (1) the population size; (2) the number of generations; (3) the type of crossover and its probability; (4) the probability of mutation; (5) and the random seed used to randomly initiate the first population of solutions (Deb et al. 2000). These genetic parameters are utilized by the multi-objective optimization module to control the evolution of the solutions generated during the optimization process which runs until completing the specified number of generations. After completing the optimization process, the results are retrieved and visualized in the output phase.

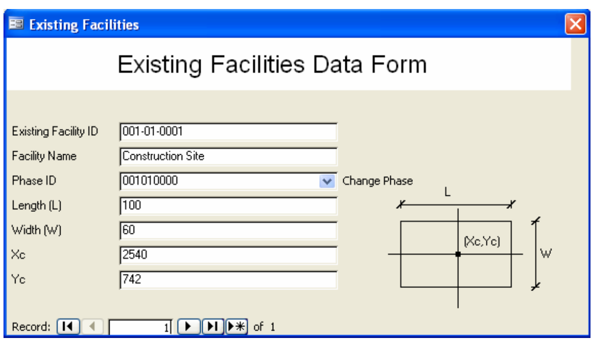

Figure 3: Existing Facilities Input Data

OUTPUT PHASE

The output phase is designed to enable the retrieval of the optimal trade-offs between construction operations safety and travel cost of resources on site. The output phase also facilitates invoking the visualization module to help visualize optimal site layout plans in a CAD software environment, as shown in Figure 4. This phase operates in two steps which are designed to: (1) retrieve the generated optimal trade-off solutions from the system database and display the trade-off curve between safety and cost, allowing the planner to navigate through these generated solution, as shown in Figure 4; and (2) export selected optimal site layout plans to the visualization module.

Figure 4: System Output

VISUALIZATION MODULE

The main purpose of the visualization module is to transform the generated optimal site layout solutions into a form that can be readily exported to and visualized in a Computer Aided Drafting environment such as AutoCAD. To accomplish this, the visualization module (1) retrieves the dimensions of each temporary facility from the temporary facilities table; (2) calls a routine to prepare a script file with the necessary AutoCAD commands needed to draw the temporary facilities; and (3) starts AutoCAD and executes the script file commands to draw the temporary facilities. The user can then visualize the site layout plan and perform further analysis to ensure that the site layout plan conforms to any other project needs.

APPLICATION EXAMPLE

An application example is analyzed to illustrate the use of the DSS and demonstrate its capabilities in generating optimal trade-offs between safety and cost in the design of site layouts. The analyzed example project involves site layout optimization of a commercial building (100 x 150 m^2), as shown in Figure 5. The dimensions of the building and those of all temporary facilities are illustrated in Table 1. In this example, a crane is located at the west side of the building as shown in Figure 5. The model facilitates the storage of all this necessary data through the previously described graphical user interface (e.g. see Figure 3). After providing all the necessary site data and genetic algorithm parameters, a construction planner can invoke the optimization module to start the optimization process. The DSS then starts to run a series of optimization generations attempting to evolve the population to a set of optimal site layout plans. After the termination of the optimization process, the planner can start the process of retrieving the trade-off solutions by invoking the visualization module. Finally, the user can navigate through the generated optimal site layout solutions and visualize any of these optimal solutions by selecting the “View Site Layout” option, as shown in Figure 4. The visualization module then runs the procedure designed to export the selected optimal site layout solution to AutoCAD and automatically draws this optimal solution, as shown in Figure 5.

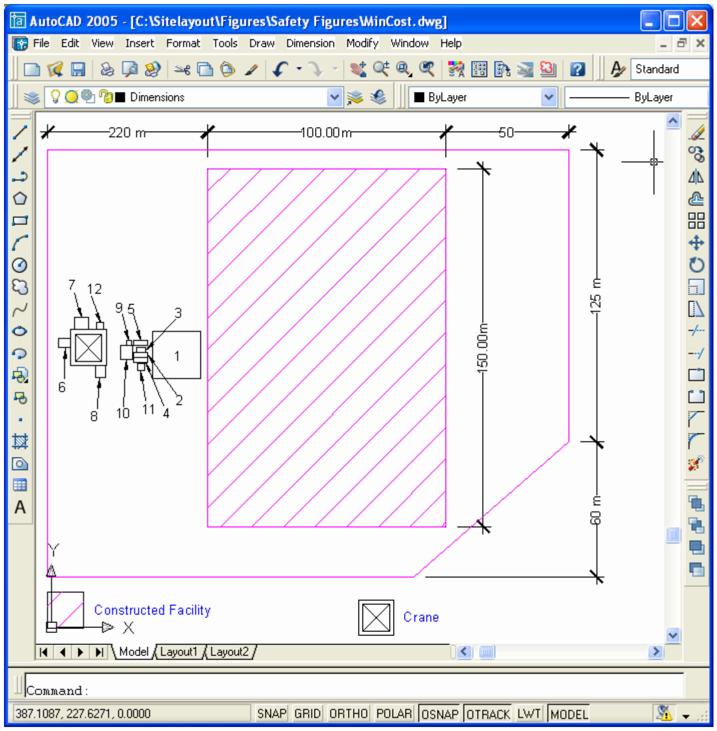

Figure 5: Visualizing Selected Site Layout in AutoCAD

Table 1: Temporary Facilities Attributes

Facility ID	Facility Description	Length in m	Width in m
1- Temporary Facilities			
1	Parking area	20	20
2	Site office I	20	5
3	Site office II	12	5
4	Site office III	20	5
5	Site office IV	20	5
6	Steel fabrication yard	5	4
7	Laydown area	6	5
8	Storage facility	4	5
9	Generator	2	2
10	Toilets	5	6
11	Fire equipment storage	3	3
12	Inflammable materials storage	3	3
2- Facilities With Fixed Locations			
F*	Facility to be constructed	100	150
C**	Crane	15	15

* The coordinates of the center of the constructed facility are (250, 150)
** The coordinates of the center of the crane are (150, 150)

CONCLUSIONS

This paper presented the development of a multi-objective decision support system for site layout planning that facilitates the simultaneous maximization of construction operations safety and efficiency. The system was developed in four main modules: (1) a multi-objective optimization module to quantify and optimize the impact of site layout planning on construction operations safety and the travel cost of resources on site; (2) a relational database module to facilitate the storage and retrieval of construction site layout data and the generated optimization results; (3) a user interface module to facilitate the input of project data and the analysis of the generated optimal site layout plans; and (4) a visualization module that interfaces with external CAD software to support the visualization of the generated optimal site layout plans. An application example was analyzed to illustrate the use of the model and demonstrate its capabilities in: (1) generating optimal trade-off solutions between construction operations safety and travel cost of construction resources on site; (2) visualizing the trade-off between these important planning objectives; and (3) providing seamless integration with commercially available CAD software to enable the construction planner visualize the generated optimal site layout plans. These capabilities should prove useful to construction site layout planners and contribute to advance the optimization of site layout planning.

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REFERENCES

Anumba, C., and Bishop, G. (1997). "Importance of Safety Considerations in Site Layout and Organization." Canadian Journal of Civil Engineering, 24(2), 229 – 236.

Armour, G. C. and Buffa, E.S. (1963). "A Heuristic Algorithm And Computer Simulation Approach to Relative Location of Facilities." *Management Science*, 9(1), 294-309.

Bureau of Labor Statistics (BLS). (2004). "*Numbers and rates of fatal occupational injuries by industry division, 2002*." <http://www.bls.gov/iif/oshwc/cfoi/cfch0001.pdf> (January 2004).

Dawood, N., and Marasini, R. (2001). "Stockyard Layout Management for Precast Concrete Products Using Simulation." *Proceedings of the CIB-W78 International Conference, IT in Construction in Africa*, Mpumalanga, South Africa, 26/1-13.

Deb, K., Agrawal, S., Pratab, A., and Meyarivan, T. (2000). "A Fast Elitist Non-Dominated Sorting Genetic Algorithm for Multi-Objective Optimization: NSGA-II." *KanGAL report 200001*, Indian Institute of Technology, Kanpur, India.

El-Rayes, K., and Khalafallah, A. (2005). "Trade-off between Safety and Cost in Planning Construction Site Layouts," *Journal of Construction Engineering and Management*, ASCE, 131(11), 1186-1195.

Hamiani, A. (1989). "Knowledge Representation for the Site Layout Problem." *Sixth Conference on Computing in Civil Engineering*, New York, 283 – 289.

Hegazy, T., and Elbeltagi, E. (1999). "EvoSite: An Evolution-Based Model for Site Layout Planning." *Journal of Computing in Civil Engineering*, ASCE, 13 (3), 198-206.

Kumara, S. R. T, Kashyap, R. L. and Moodie, C. L. (1988). "Application of Expert Systems and Pattern Recognition Methodologies to Facilities Layout Planning." *International Journal of Production Resources*, 26(5), 905-930.

Li, H., and Love, P. E. D. (1998). "Site-Level Facilities Layout Using Genetic Algorithms." *Journal of Computing in Civil Engineering*, ASCE, 12 (4), 227-231.

Mawdesley, M. J., Al-jibouri, S. H., and Yang, H. (2002). "Genetic Algorithms for Construction Site Layout in Project Planning. " *Journal of Construction Engineering and Management*, ASCE, 128 (5), 418-426.

National Institute for Occupational Safety and Health (NIOSH). (2000). "Worker Health Chartbook, 2000." *DHHS (NIOSH) 2000-127*, USA.

Rob, P., and Coronel, C. (2002). Database Systems: Design, Implementation, and Management, Thomson Learning, Boston, MA.

Tam, K. Y. (1992). "Genetic Algorithms, Function Optimisation, and Facility Layout Design." *European Journal of Operational Research*, 63, 322-346.

Tawfik, H. M., and Fernando, T. (2001). "A Simulation Environment for Construction Site Planning." *5th Int. Conf. Information Visualisation*, London, UK.

Tommelein, I. D., and Zouein, P. P. (1993). "Interactive Dynamic Layout Planning." *Journal of Construction Engineering and Management*, ASCE, 119 (2), 266-287.

Tommelein, I. D., Levitt, R. E., and Hayes-Roth, B. (1992). "SightPlan Model for Site Layout.", *Journal of Construction Engineering and Management*, ASCE, 118 (4), 749-766.

Tommelein, I. D., Levitt, R. E., Hayes-Roth, B., and Confrey, T. (1991). "SightPlan Experiments: Alternate Strategies for Site Layout Design." *Journal of Computing in Civil Engineering*, ASCE, 5 (1), 42-63.

Yeh (1995). "Construction-site Layout Using Annealed Neural Network." *Journal of Computing in Civil Engineering*, ASCE, 9(3), 201-208.