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Optimizing the Schedule of Dispatching Construction Machines through Artificial Intelligence

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Most construction projects involve use of construction machines, construction plant manager has to consider both timeliness and flexibility to develop an efficient schedule of dispatching construction machines, which can balance the operations at different construction sites. In this paper, we constructed an optimization model with multi-target as construction quality, time limit, efficiency and cost. The model consists of a database, a rule-based system and multi-target decision making modules. The database includes detailed data about construction machine types and their properties. The rule-based system module provides rules, which are utilized by inference engine for determining the most proper construction machine type. Ultimately, a final decision is made for the most proper construction machine among the alternatives of the same type using the information axiom of axiomatic design principles. In order to verify the validity of the model, evaluation of alternatives is made for the cases of both complete and incomplete information.

1. Introduction

Construction machine selection is an important activity in the design of an effective construction operation system design. Dispatching appropriate construction machine can decrease constructing times, improve construction machine utilization and increase quantities. Construction machine operating can account for 30–55% of the total cost, and efficient construction machine operating can be primarily responsible for reducing a construction site’s operating cost by 15–30%. Therefore, determination of proper construction machine dispatching strategy is very important for reduced costs and increased profits. As a wide variety of construction machine is available today, each having distinct characteristics and cost that distinguish from others, determination of the proper construction machine for a designed construction operation is a very complicated decision.

There are various approaches focused on the solution of this complicated problem. Intelligent computer systems have been developed such as expert systems and decision support systems for the dispatching of construction machine.

In artificial intelligence, an expert system is a computer system that emulates the decision-making ability of a human expert. Expert systems are designed to solve complex problems by reasoning about knowledge, represented primarily as if–then rules rather than through conventional procedural code. One of the most successful applications of experts systems is SEMH: selection of equipment for material handling. SEMH searches its knowledge base to recommend the degree of mechanization, and the type of material handling equipment to be used, based on some characteristics (Fonseca et al., 2004). Malmborg (Malmborg et al., 1987) has developed a prototype expert system considering 17 equipment attributes and 47 devices for industrial truck type selection.

A decision support system (DSS) is a computer-based information system that supports business or organizational decision-making activities. DSSs serve the management, operations, and planning levels of an organization and help people make decisions about problems that may be rapidly changing and not easily specified in advance. Decision support systems can be either fully computerized, human-powered or a combination of both. DSSs include knowledge-based systems. A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from a combination of

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raw data, documents, and personal knowledge, or business models to identify and solve problems and make decisions.
This work is organized as follows. Section 2 describes related work. In Section 3 we explain factors of impacting the schedule of dispatching construction machines. In Section 4 structure of optimal scheduling model is introduced, and the probability equation of success by integrating the system probability density function over the entire design range is given. In Section 5 evaluation method of alternatives is made for the cases of incomplete information is proposed. In Section 6 we conclude this paper.

2. Related work

Construction is one of the most common and essential operations in civil engineering projects, its procedures deal mainly with earth excavation, transportation and dumping, all of which require construction machine operations. Considerable work has been done developing models or approaches to facilitate the planning of construction machine operations.
Marzouk and Moselhi (Marzouk et al., 2003) have provided a simulation model to optimize the use of available resources. Moselhi and Alshibani (Moselhi et al., 2009) have proposed an optimization of earthmoving operations, which focused on selecting suitable machine equipment. Jayawardane and Harris (Jayawardane et al., 1990) proposed a method which was used to minimize cost while completing the projects within the targeted time frame. Son and Mattila (Son et al., 2005) propose a model which was used to balance the utilization of resources throughout the project duration.
Existing works for dispatching construction machines have several limitations. They always have been done from the general contractors' point of view. In other words, the previously developed models are designed to dispatch construction machines for only a single project.
Most of these models or approaches do not consider all of the technical, strategic and economic criteria simultaneously in dispatching the most appropriate construction machine. They also cannot evaluate the alternatives for the cases of both complete and incomplete information.
Approaches that include more than one measure of performance in the evaluation process are termed multi-attribute or multi-criteria decision methods. The advantage of these methods is that they can account for both financial and non-financial impacts.
The main goals and contributions of this paper are the use of computer simulation methods and axiomatic design approach, with the objective of minimizing the time for constructing an optimal dispatch model to deal with construction machines schedule problems.

3. Factors of impacting the schedule of dispatching construction machines

There are many factors that impact the schedule of dispatching construction machines, the main factors are as follows:

3.1 Travel time between the construction site and the landfill site

The travel time between the construction site and the landfill site is not easy to predict exactly, as it is determined by the distance between the locations, the speed of the transportation machines, and traffic conditions. To avoid delays, the dispatching manager usually assigns a higher priority to job sites that have a large volume of earth to be removed. However, such an approach increases the chance of interrupting the work process at a job site that has a faster but lower-volume earthmoving operation. Therefore, the travel time between the job site and landfill site is important when deciding the schedule of the construction machines. In practice, the average travel time can be estimated from historic data.

3.2 Working time at the job site

The time spent on working at the job site varies with the type of construction activity, which could affect the frequency with which machines are dispatched to the same job site. For example, the faster the constructing operation at a job site, the shorter is the interval between dispatches of machines to that job site. If the construction machines cannot arrive at the job site in time, it is possible that the whole job site will be idle, which will impact the work process at the job site tremendously. The dispatching manager may assign as many construction machines as possible to the busiest job site; however, such an approach might cause time wastage if the construction machines need to line up and wait for working.

3.3 Number of construction machines needed

The number of construction machines needed depends on the amount of earth-work scheduled to be removed, the loading capacity of the construction machines and the road's regulated weight limit. For example, one construction site schedules 300 m^3 of earth-work to be removed. Although a truck can be loaded up to 20 m^3, the regulation for the road it must travel may only permit the truck to be loaded with 15 m^3. As a result, the number of trips that trucks make to this job site increases from 15 to 20, and the time needed to finish the earthmoving process is extended.

4. Structure of optimal scheduling model

The optimal scheduling model is developed in order to simplify the selection process of the most appropriate construction machines, consists of the following modules as shown in Figure 1.

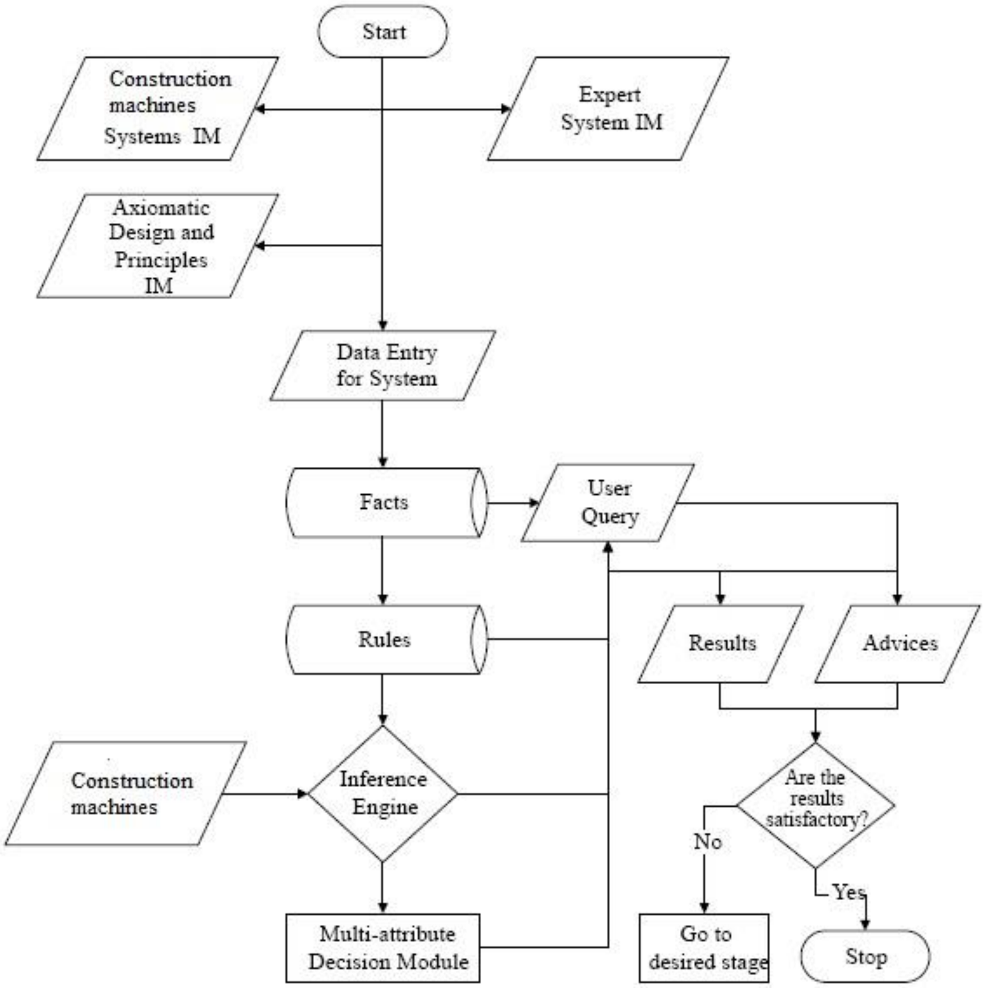

Figure 1: Flow-process diagram of the optimal scheduling model

Construction machines are classified into main groups of trucks, excavators, cement mixers, cranes, forklift and boring machines. This module includes examples of 46 move construction machine types with their performance criteria.

The model includes 137 rules in the knowledge base, assuming a 100% confidence factor. These rules are acquired from construction machines dispatching managers and the literature about construction machines. Arity PROLOG language is used to define these rules so that they will not be badly influenced by the variations in the methods or the changes in the knowledge base. Some examples of knowledge base rules, which are in accordance with IF–THEN structure, are presented below.

Rule 37:

IF Function type_move and
Move area and path_fixed and
Floor space_available
THEN Most proper move type_conveying.

Rule 78:

IF Move type_conveying and
Individual type_packaged and
Move direction_horizontal and
Operation control_uncontrollable and
Bottom surface_not flat
THEN Most proper conveyor type_Wheel conveyor.

Rule 79:

IF Move type_conveying and
Individual type_packaged and
Move direction_horizontal and
Operation control_controllable and
Bottom surface_not flat and
Material weight_X!100 kg
THEN Most proper conveyor type_Belt conveyor.

The most important concept in axiomatic design is the existence of the design axioms. The first design axiom is known as the independence axiom and the second axiom is known as the information axiom.
The independence axiom states that the independence of functional requirements (FRs) must always be maintained, where FRs are defined as the minimum set of independent requirements that characterizes the design goals (Suh, 1995). In the real world, engineers tend to tackle a complex problem by decomposing it into sub-problems and attempting to maintain independent solutions for these smaller problems. This calls for an effective method that provides guidelines for the decomposition of complex problems and independent mappings between problems and solutions.
The information axiom states that among those designs that satisfy the independence axiom, the design that has the smallest information content is the best design (Suh et al., 1998).
Information is defined in terms of the information content, I_i, that is related in its simplest form to the probability of satisfying the given FRs. I_i determines that the design with the highest probability of success is the best design. Information content I_i for a given FR_i is defined as Eq(1).

$$I_i = \log_2\left(\frac{1}{p_i}\right) \qquad (1)$$

where p_i is the probability of achieving the functional requirement FR_i and log is either the logarithm in base 2. The definition of information follows the definition of Shannon, although there are operational differences. Because there are n FR_s, the total information content is the sum of all these probabilities. When all probabilities are one, the information content is zero, and conversely, the information required is infinite when one or more probabilities are equal to zero.
In any design situation, the probability of success is given by what designer wishes to achieve in terms of tolerance (design range) and what the system is capable of delivering (system range).
As shown in Figure 2, the overlap between the designer-specified 'design range' and the system capability range 'system range' is the region where the acceptable solution exists. Therefore, in the case of uniform probability distribution function pi may be written as Eq(2).

$$p_i = \left(\frac{Common\ range}{System\ range}\right) \qquad (2)$$

Therefore, the information content is equal to

$$I_i = \log_2\left(\frac{System\ range}{Common\ range}\right) \qquad (3)$$

The probability of achieving FR_i in the design range may be expressed, if FR_i is a continuous random variable, as

$$p_i = \int_{dr^1}^{dr^u} p_s(FR_i)\,dFR_i \qquad (4)$$

$p_s(FR_i)$ is the system probability density function for FR_i.

Eq. (4) gives the probability of success by integrating the system probability density function over the entire design range.

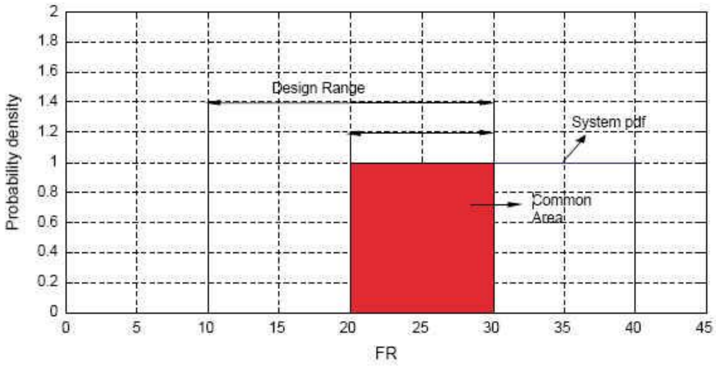

Figure 2: Design range, system range, common range and probability density function of a FR

In Figure 3, the area of the common range (A_{cr}) is equal to the probability of success p_i. Therefore, the information content is equal to

$$I = \log_2\left(\frac{1}{A_{cr}}\right) \tag{5}$$

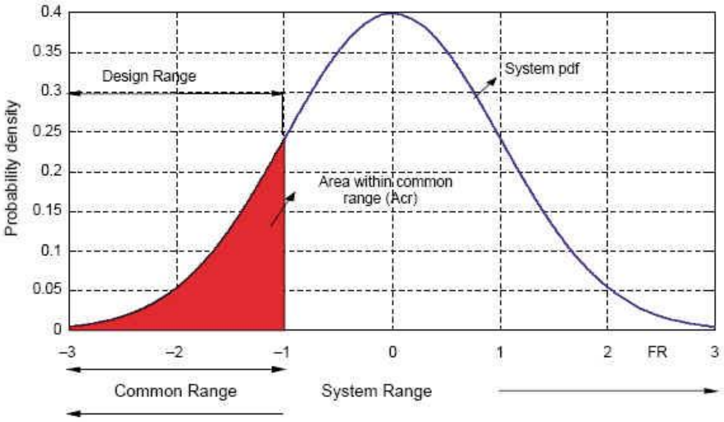

Figure 3: Area within common range

5. Fuzzy information axiom for incomplete information

The crisp information axiom approach can be used for the solution of decision-making problems under certainty. This approach cannot be used with incomplete information, since the expression of decision variables by crisp numbers would be ill defined. The definition and formulation of the developed fuzzy approach are given in the following.

The data relevant to the criteria under incomplete information can be expressed as fuzzy data. The fuzzy data can be linguistic terms, fuzzy sets, or fuzzy numbers. Linguistic terms are first transformed into fuzzy numbers. Then these fuzzy sets are assigned crisp scores. The following numerical approximation system are proposed to systematically convert linguistic terms to their corresponding fuzzy numbers.

In the fuzzy case, we have incomplete information about the system and design ranges. The system and design range for a certain criterion will be expressed by using 'over a number', 'around a number' or 'between two numbers'. Triangular or trapezoidal fuzzy numbers can represent these kinds of expressions. We now have a membership function of triangular or trapezoidal fuzzy number (TFN), whereas we have a probability density function in the crisp case.

The common area, which is the intersection area of triangular or trapezoidal fuzzy numbers, between design range and system range is shown in Figure 4.

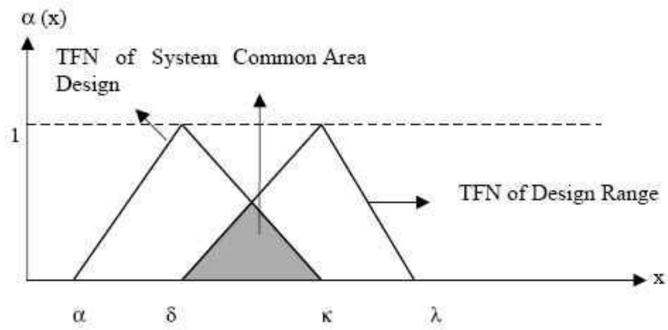

Figure 4: The common area of system and design ranges

6. Conclusions

A schedule that satisfies the requests from different construction operations is needed to quickly generate for dispatch planning manager. However, completing such an operation is not an easy task and, in practice, depends mainly on the experience of the manager. In this paper a decision support model, which considers both technical and economic criteria in dispatching construction machines process, is presented. The rule-based system module provides rules, which are utilized for determining the most proper construction machine type. Ultimately, a final decision is made for the most proper construction machine among the alternatives of the same type using the information axiom of axiomatic design principles.

Reference

Fonseca D., Uppal G., Greene J., 2004, A knowledge-based system for conveyor equipment selection, Expert Systems with Applications, 26, 615- 623, DOI: doi:10.1016/j.eswa.2003.12.011

Jayawardane K., Harris C., 1990, Further development of integer programming in earthwork optimization, Journal of Construction Engineering and Management, 1, 18-34, DOI: 10.1061/(ASCE)0733-9364(1990)116:1(18)

Malmborg J., Agee H., Choudhary V., 1987, A prototype expert system for industrial truck type selection, Industrial Engineering, 3, 58-65

Marzouk M., Moselhi O., 2003, Object-oriented simulation model for earthmoving operations, Journal of Construction Engineering and Management, 2, 173-181, DOI: 10.1109/WSC.2000.899188M

Moselhi O., Alshibani A., 2009, Optimization of earthmoving operations in heavy civil engineering projects, Journal of Construction Engineering and Management, 10, 948 -954, DOI: 10.1061/(ASCE)0733-9364(2009)135:10(948)

Son, J., Mattila K., Myers D., 2005, Determination of haul distance and direction in mass excavation, Journal of Construction Engineering & Management, 3, 302-309, DOI: 10.1061/(ASCE)0733-9364(2006)132:8(897)

Suh, P., 1995, Designing-in of quality through axiomatic design, IEEE Transactions on Reliability, 2, 256-264, 10.1109/24.387380

Suh, P., Cochran, S., Paulo, L., 1998, Manufacturing system design, Annals of the CIRP, 2, 627-639, DOI: 10.1016/S0007-8506(07)63245-4