OPTIMISING CONSTRUCTION METHOD SELECTION STRATEGIES IN AN INTEGRATED DECISION SUPPORT ENVIRONMENT: RESULTS OF APPLICATION TO EARTHWORKS OPERATIONS

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Although the construction industry has witnessed a proliferation of techniques for resource selection, most of these techniques have not given adequate attention to the problems of cross utilisation of data. In practice, there remains the need for efficient use of construction data for various decision analysis problems within an integrated project management environment. This paper discusses the results of an application designed to address this problem in the area of resource selection. The results demonstrate the use of generic objective functions to generate some decision-making parameters in project management.

Keywords: construction databases, DSS, OLE-automation, project management, resource optimisation.

BACKGROUND

Planning and decision making in construction is a process characterised by various complexities. One general type of decision problem involves scheduling resources to various activities that are required for a successful completion of project. Such resource allocation problems often range from the very simple to the highly complex.

In the construction industry, efficient management of construction projects requires making decisions on the best way to allocate available resources to various tasks. The level of complexity in the decision making process often depends on the project characteristics (such as size, type, number of tasks, etc). A common decision making problem involves determining the type and number of resources that are required in a construction process and then deciding the most cost-effective way to allocate those resources. Other aspects of the decision include selecting the most appropriate construction method and/or determining the most suitable operational sequence to execute the tasks to ensure effective production control.

In complex decision making it is always desirable to sift specific sets of data from a large database and translate/present the retrieved information in a form that is easily understood and usable by the manager for quick decision making. In any situation, an ability to make quick and efficient decisions at the appropriate level, are the basic prerequisites for successful completion of a project and the continued growth of a business organisation. Such success manifests itself in completing projects on time, within budget and results in *goodwill* amongst all project participants.

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The paper gives snapshots of previous solution strategies in the problem domain and the methodology adopted in this work. An overview of the application, and some output results are also given and the paper concludes with some highlights and scope for further work.

Previous solution strategies and problem definition
The problem of decision making in resource allocation has been approached from different frontiers in the production/operations research community. In the process, various authors and researchers have applied different techniques and paradigms. These paradigm shifts have progressed from conventional heuristics to; mathematical programming (Easa 1987, Jayawardne and Harris 1990), knowledge based expert systems (Alkass and Harris 1988, 1991) , and decision support systems - DSS (Shen and Grivas 1994, Tah and Howes 1994, Tah 1996).

From a review of existing literature, two distinct problems were identified and known to dominate resource allocation problems. For instance;

> Alkass and Harris (1988) highlighted "…the enormous problem of trying to represent all earthwork activities in one expert system", while Jayawardne and Harris (1990) noted in their work that "... for large projects the formulation of the problem became very tedious because of the increased number of equations involved…"

Thus the two dominant problems can be summed up as scalability and combinatorial explosion.

The problem with resource optimisation is further exacerbated by the fact that in real life and within an integrated construction management environment, a typical user may not only be interested in selecting a few optimisation parameters during a decision-making session, the user may also be interested in active involvement and navigating ("checking out") other functionality and scenarios that form part of the entire decision making process. This further calls for solutions that are generic and yet flexible enough to take into consideration the psychology and various levels of cognitive styles and behavioural characteristics of different users when engaged in a decision analysis. DSS is one of the attempts by researchers to improve the decision making process.

The development of DSS stem from the increasing desire to address some of the limitations of previous solutions, and in particular from the realisation that system performance can best be improved by integrating quantitative and qualitative models with an organisation's databases (Davis 1988, Sprague and Watson 1993). This paper addresses the outlined requirements with respect to construction DSS.

METHODOLOGY

The methodology adopted in the research was tailored to address the specific outlined requirements of the problem domain as already highlighted. This includes, a review of resource assignment procedures, investigation of resource assignment data, including identification of the key decision points in solving such problems, mathematical formulation of the problem, abstraction of the attributes and variables required to solve the mathematical model representation (data modelling), a visual representation of the problem domain and solution using the object-oriented paradigm, prototypical implementation of the solution, and prototype validation using a typical earthworks project from a textbook. Each of the above sequences is discussed further in the following sections.

Resource assignment and construction method selection procedures

The first of phase of the work involved a review of the various processes and procedures involved in resource allocation at the highest level of abstraction possible. The objective was to establish generic activities, construction methods and corresponding resource requirements for different types of projects. The following are identified key procedures and decision points in a typical resource assignment and construction method selection problem;

1. identify project characteristics (size, duration, complexity, quantity etc)
2. identify the different tasks and geotechnical (resource productivity) factors
3. identify both the required and available resources
4. assign available resources to the tasks in the *best possible* way and
5. optimise the resource assignment - select the best combination of resources to satisfy project constraints with respect to; duration and budgetary requirements.

The above procedures highlight the need to integrate resource planning and cost control data in order to facilitate the decision making process throughout an organisation. It also highlights the fact that none of the above five procedures can be carried out purely in isolation from the other.

Hypothesis formulation

Following the identification and definition of the problem, two sets of hypothesis were formulated as a basis for proposing any new solution strategy in the problem domain;

- H1: That resource allocation problem (in earthworks) is a non linear multidimensional, multi-attribute problem that demands a more elaborate solution strategy that would incorporate the achievements of previous works whilst addressing their limitations.
- H2: That because of the multidimensional characteristics and the non-linearity associated with the problem, a hybrid solution that integrates mathematical models and databases, with appropriate optimisation algorithms would provide a more robust solution than either pure mathematical programming, heuristics, or knowledge bases only.

Mathematical formulation of the problem

A quantitative model that represents analytical computations in the resource allocation problem was formulated. The mathematical model expresses the project costs and duration in terms of task details, resource productivity attributes, and economic data such as resource unit cost. The general model for the cost and duration constraint is given by equations 1 and 2 respectively;

$$C = \sum_i \sum_k \sum_{n \in N_{i,j}} \left[\frac{Q_{mt}(i, j, n) * U_{rt}(i, j, N)}{R_{ot} * C_f} \right] \qquad (1)$$

$$\sum_i \sum_j \left[\frac{Q_{mt}(i, j, N)}{R_{ot} * C_f} \right] \leq D_t \qquad (2)$$

Where C denotes the total cost of executing the various tasks over a section i, j,

Q_{mt} = quantity of task involved;

U_{rt} = unit cost of resource R assigned to perform a given task t;

R_{ot} = the output of the given resource assigned to task t;

C_f = the resource productivity factor; and

D_t is the task duration.

Data modelling

Detailed abstraction of the problem and a mathematical representation were undertaken as part of the literature review. The focus was on identifying generic data attributes and variables required to solve the problem in a given domain of construction activity as expressed in the mathematical model. Data attributes were identified for projects, tasks, and the resource(s) assigned to a particular task. Existing literature formed the predominant source of data in order to ensure uniformity, and avoid the risk of bias towards a particular vendor's equipment but further validation of specific makes of equipment will be undertaken in due course.

The final data model is built upon three fundamental sets of class objects;

- a project that consists of at least one task
- the task(s) at hand required to be completed including any material that may be borrowed or removed from site during construction - hence each task completion is a transformation process within the project that owns it, and
- the resources that are required to execute the above tasks

The related project, tasks and resources were identified as persistent objects in the model and mapped into a relational database structure within the data repository.

Visual representation of the solution: the components diagram

Object oriented (OO) paradigm was the technique employed to develop a process model. The static object model was developed using a visual modelling tool (Rational Rose) and this facilitated identification of various collaborative components that communicate within the decision making environment (Figure 1).

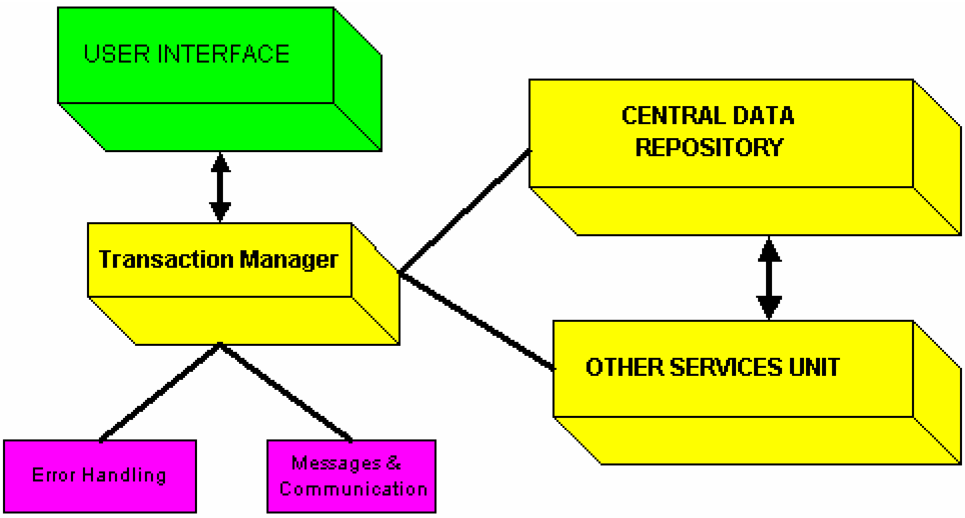


Figure 1: Components diagram of the DSS illustrating the interaction between objects

The component diagram is a schematic illustration of how the various units of the application communicate with, and/or transmit messages between one another. It also provides a high level of the application architecture. The diagram defines a simple but powerful and expressive model with the following features;

Generic input forms for data entry and problem definition
The model allows authenticated users to enter the data for projects, tasks and resources using a set of input forms. These sets of data define characteristics of the optimisation problem at hand, and are entered using the functionality provided in the user interface (Figure 2).

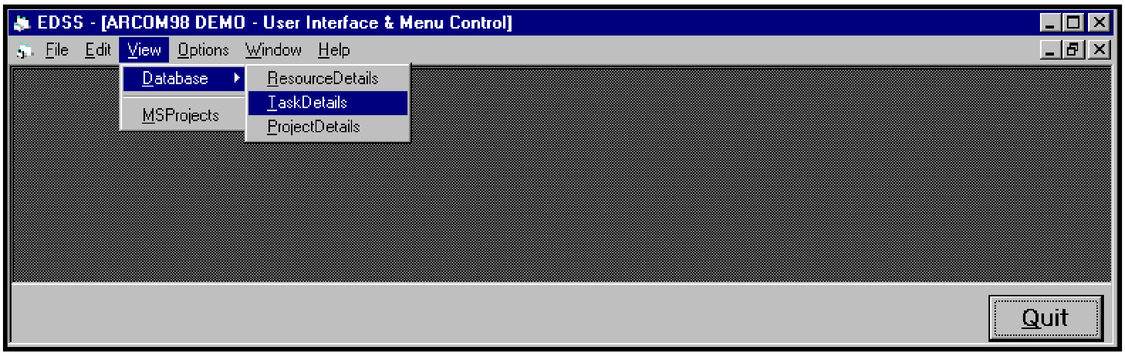
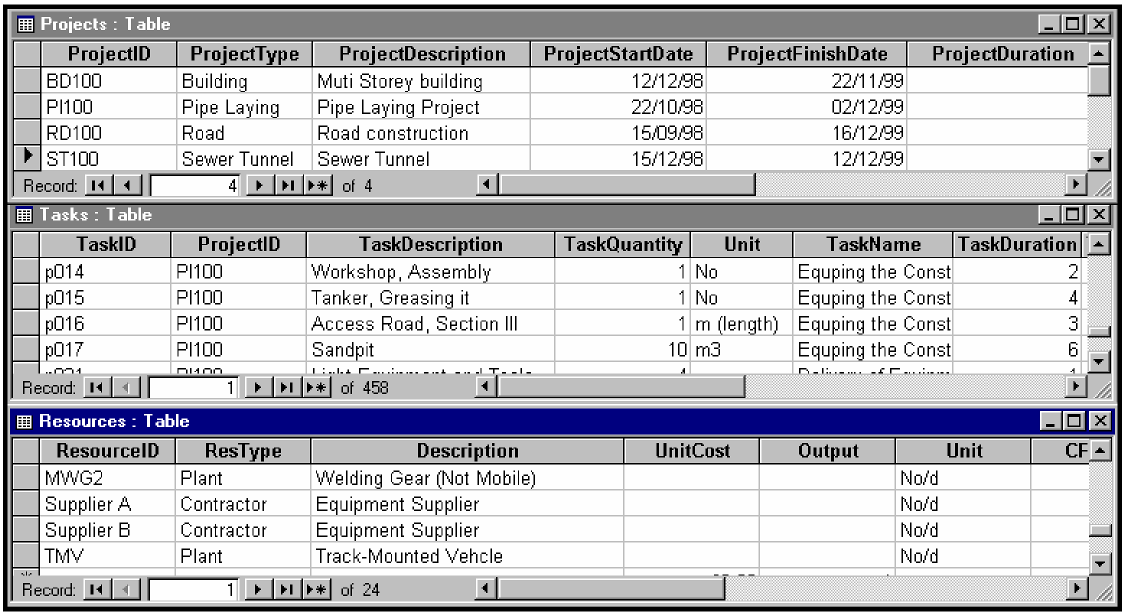


Figure 2: An interface for integrated DSS in the project management environment

Such attributes include the quantity and duration of tasks for a given project. It also includes the productivity and economic attributes of resources that are available for the task(s). Some examples of resource attributes include; output, correction factor, and unit costs (hourly rates) etc. The entered attributes are then mapped into appropriate sections of a relational database (Figure 3).



Projects : Table

ProjectID	ProjectType	ProjectDescription	ProjectStartDate	ProjectFinishDate	ProjectDuration
BD100	Building	Muti Storey building	12/12/98	22/11/99	
PI100	Pipe Laying	Pipe Laying Project	22/10/98	02/12/99	
RD100	Road	Road construction	15/09/98	16/12/99	
ST100	Sewer Tunnel	Sewer Tunnel	15/12/98	12/12/99	

Record: 4 of 4

Tasks : Table

TaskID	ProjectID	TaskDescription	TaskQuantity	Unit	TaskName	TaskDuration
p014	PI100	Workshop, Assembly	1	No	Equping the Const	2
p015	PI100	Tanker, Greasing it	1	No	Equping the Const	4
p016	PI100	Access Road, Section III	1	m (length)	Equping the Const	3
p017	PI100	Sandpit	10	m3	Equping the Const	6

Record: 1 of 458

Resources : Table

ResourceID	ResType	Description	UnitCost	Output	Unit	CF
MWG2	Plant	Welding Gear (Not Mobile)			No/d	
Supplier A	Contractor	Equipment Supplier			No/d	
Supplier B	Contractor	Equipment Supplier			No/d	
TMV	Plant	Track-Mounted Vehcle			No/d	

Record: 1 of 24

Figure 3: A user's view of the database

Resource allocation / construction method selection using GA Optimiser
The model also allows users to make a preliminary assignment of available resources to the tasks using the attributes mapped into and stored in the repository. The system then uses this initial assignment to generate a set of initial data which is subsequently

used for combinatorial optimisation by a Genetic Algorithm Optimiser. The genetic model is designed to encapsulate information related to a given resource with respect to cost and duration as well as the associated constraints (i.e. a one-to-one genetic mapping). This process is used to identify the optimum resource allocation over a feasible region.

Users can then enter the optimised result in a designated database table, and subsequently view the graphical representation using a project management package. In addition users can opt for a panoramic view of selected details of the project, tasks or resources that provide them with relevant decision making parameters at the appropriate level (Figures 4a - 4c). Finally updates can be performed while in the project management module and such updates will be exported back to the appropriate sections of the database. All these functionalities are built into the application by using OLE automation.

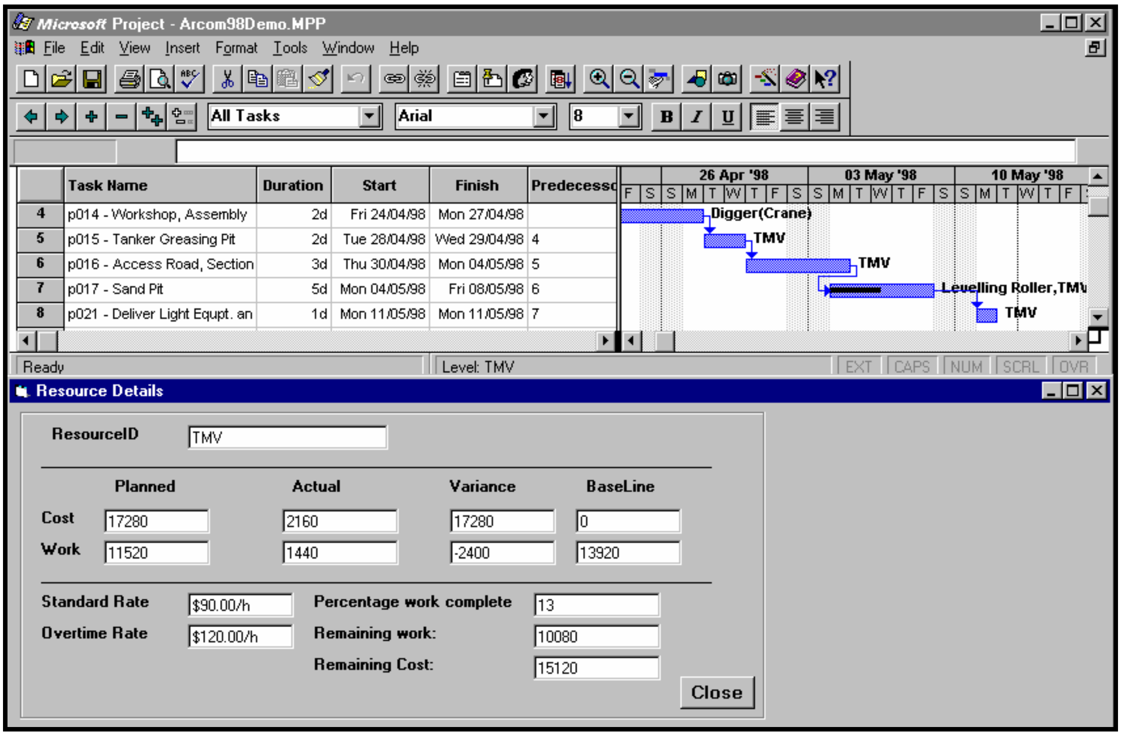


Figure 4a: A user's view of project schedule and resource details

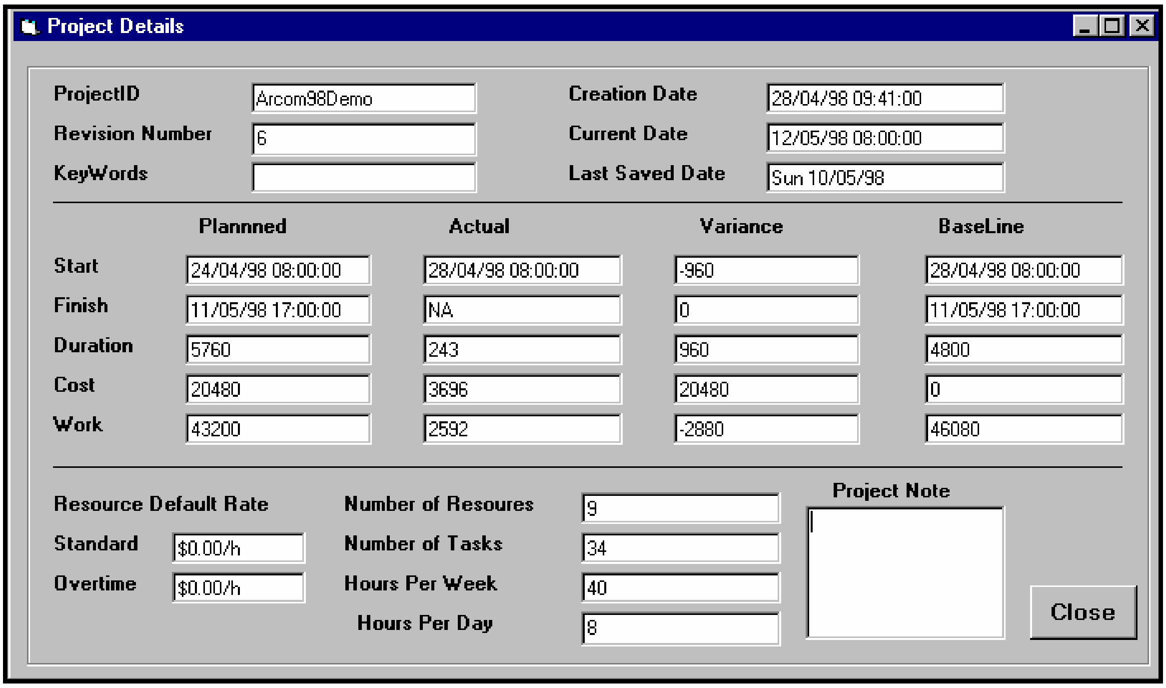


Figure 4b: A user's view of project details

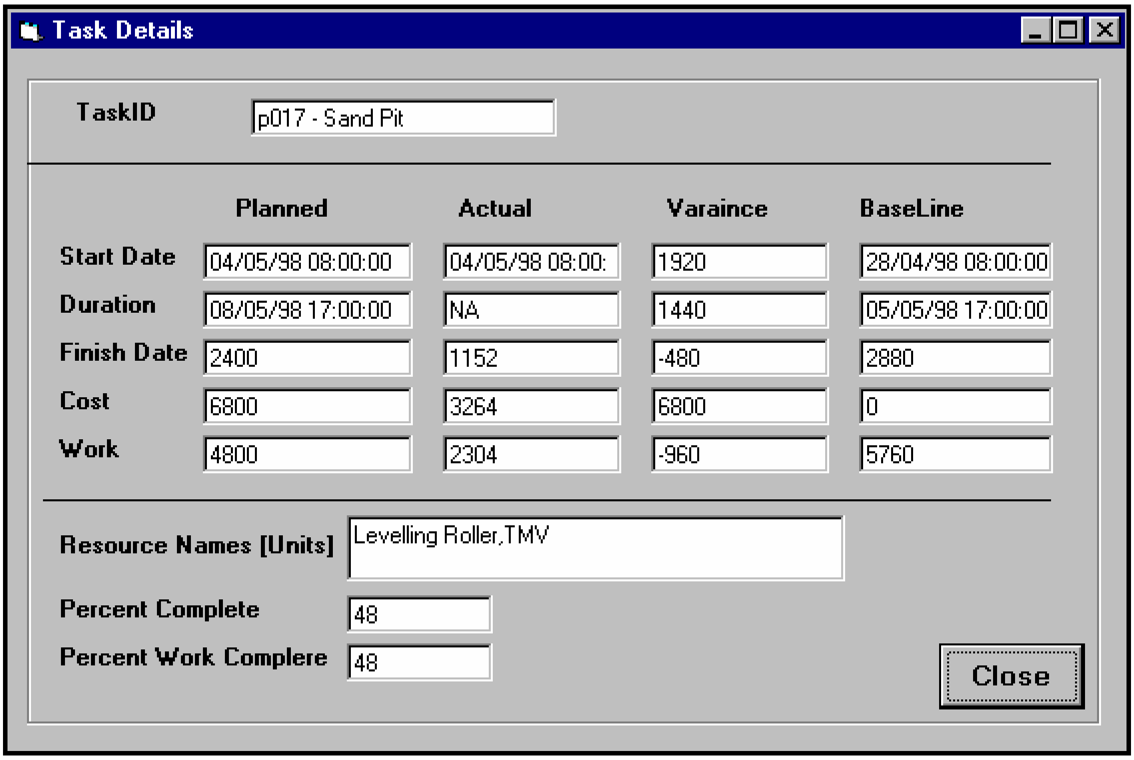


Figure 4c: A user's view of task details

IMPLEMENTATION IN A PROTOTYPE, AND CASE STUDY EXAMPLE

Decisions were taken on the programming languages required for implementation. The major determinant of the programming languages was the ease of use for rapid prototyping in an interactive windows environment, and object oriented capabilities. Visual basic and Visual C++ were chosen because together, they satisfy these criteria. Visual basic was used to design the user interface and incorporate the OLE automation functionalities that form a substantial capability of the application, while Visual C++ was used to develop the GA optimiser.

The prototype validation was performed using a practical earthworks problem :- ”Optimisation and control inspection of construction time for a pipe-laying contract” (Carvalbo and Turner 1969). The project involves laying a pipeline of defined diameter into a trench to a specified depth and then backfill the trench. Ground conditions and profile of the site are also provided in the contract documents.

The example project illustrates a two stage process to the optimisation of a project with respect to resource assignment and construction method selection. The first stage involves assigning resources to various tasks and carrying out a combinatorial optimisation using the GA optimiser. The second stage involves translating the resource assignment into a project management network (Gantt View) and using the schedule to control the production process.

CONCLUSION AND SCOPE FOR FURTHER RESEARCH WORK

This paper has demonstrated the use of resource-based mathematical models within the framework of decision support systems (DSS) in construction management.

The results emphasise the need for integrated DSS through the application of state-of-the-art techniques such as databases, genetic algorithms, and computing technologies such as OLE-automation.

So far the prototype has been tested in a particular construction domain, a pipe laying project that has some earthwork activities. The preliminary results on the example indicates there are some scopes for extension of the work. Further work will be devoted to incorporating construction tasks and resources associated with other domains into the model.

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