INTERACTIVE VISUAL LEAN SYSTEM FOR RESOURCE PLANNING OF EARTHWORK OPERATIONS

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ABSTRACT

Poor resource planning and low productivities in road construction projects are among the major factors that contribute to cost escalation and projects' overruns. Although a number of tools and methods have been developed to enhance road construction planning and in particular earthworks planning and visualisation, current practices suggest that these tools are not practical and fragmented. The aim of this paper is to develop a practical, lean and transparent knowledge driven model to reduce the complexity of earthwork operations, improve efficiency of planning processes and reduce waste at operational phase.

In this context, this research presents an interactive visual lean system that integrates different earthwork modules (including resource productivity, profile visualisation, planning and scheduling activities) to achieve efficient and productive construction plans. The system integrates atomic model configuration for productivity calculation, profile visualisation for "Mass-haul" and "Time-distance" profile, Gantt viewer for activity planning and management.

The paper introduces the theoretical aspects of planning and scheduling in linear projects, develops system framework for the proposed model, discusses the prototype and demonstrates the prototype through a real life case study.

KEY WORDS

Visualisation tool, Integrated system, Earthwork operations, Object oriented environment, Lean Construction

INTRODUCTION AND LITERATURE REVIEW

Construction projects are inherently unpredictable and complex due to the dynamic nature of site operations. Current practices suggest that project planners carry out earthwork operations in road construction using deterministic methods based on their past experience and knowledge. This has resulted in cost and time overruns caused by the lack of inclusion and appreciation of unique risk factors. Also, there is a lack of appropriate information technology (IT) tools and methods which can be used to comprehend the construction operations and processes. Information Technology has

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the capacity to demonstrate uncertain and stochastic behaviour of different processes to predict the outcomes of construction projects.

A number of literatures have been reviewed regarding earthwork operations and IT enabled lean approaches to construction projects. Jayawardane and Price (1994) developed RESOM (Roadwork Earthwork moving Simulation Optimisation Model) to optimise earthwork operations applying linear/integer programming techniques. Liapi (2003) focused on visualisation tool to validate the construction process visually by developing collaborative decision-making construction scheduling and planning for highway construction projects. Kang et. al. (2006) used morphing (visual) techniques to simulate earthwork operations such as cutting and filling where progress of site activities are simulated and changes of ground levels due to cut and fill are visualised. Chi-Ming et. al. (2007) developed an integrated system that combines a path-finding algorithm: ripple ring, plant database and genetic algorithms for optimising the feasible alternatives. Shah et. al. (2008) proposed a model that produces weekly location plans presented in the form of time-chainage.

Over the years construction industries have been criticized for having wasteful processes, unsafe working practices and less technological innovation (Egan, 1998). Al-Sudairi et. al. (1999) presented value specification, value stream (waste elimination), flow, pull, and continuous pursuit of perfection as the lean principles. Ballard (2000) argued the planning of construction just involved scheduling activity and no resource allocation. By implementing a Lean system, it provides an opportunity to allocate the resources that minimize the risk factor of uncertainty of a project completion. Kemppainen et. al. (2004) used Dyanroad2 to support planner and contractor to optimise mass-haul, monitor and control production plan. It was used for minimizing the cost of resources and control construction schedule. Rischmoller and Alarcon (2005) presented a synergistic qualitative framework to explain theoretical lean principals on the construction process and the impacts of IT on the construction industries in order to increase communication, visualisation and mitigate complexities of construction operations. Dave et. al. (2008) suggested that there is a need of redesign the construction processes in order to integrate process, people and information to deliver efficient and safe practices. In this research context, the system demonstrates the lean principles by specifying the value, mapping the value stream, smooth process flow, pull approach and transparent model for continuous improvement. It plays an important role for earthwork operations planning in order to achieve more transparency to reduce the complexity of site operations, waste of the resources and improve resource planning that impact on project time.

Some of the commercial tools have been used for earthwork planning such as: TILOS[5] is a time-location planning tool for managing linear construction projects such as roads, rail lines, pipelines and tunnels. DynaRoad[6] is a tool that can be used for schedule, mass haulage optimisation and progress control for earthwork operations in construction projects such as roads and railways. However it lacks the functionalities to simulate the productivity and cost considering variable factors such as sets of equipment, site constraints and soil characteristics using "what if scenarios". Furthermore, users need to calculate existing and design ground level of road section separately before importing into the tool for optimisation of haulage distance and time

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5 TILOS (2010), Available at: [http://www.tilos.org]
6 DynaRoad (2010), Available at: [http://www.dynaroad.com]

location chart. One of the main shortfalls of the tools and methods produced by the above research projects is the lack of industrial applicability and practicality of using such tools on site.

The research project presented in this paper is a continuation of previous research efforts by Dawood and Castro (2009). They have developed a knowledge-based simulator dubbed RoadSIM to assist planners to select resources and determine construction cost and time. This research project aims to present a methodology that develops an interactive visual lean system to assist project managers in achieving accurate and effective resource planning and management of earthwork activities. It is hypothesized that by integrating different earthwork modules, including resource module (RoadSIM), profile visualisation, activity planning and scheduling efficient, productive and efficient and lean construction sites can be materialized.

In order to develop an interactive visual lean system, a number of objectives have been set:

- Design a framework to identify and integrate different earthwork components including resource module, activity planning module, distance optimisation and earthwork profile visualisation.
- Implement earthwork modules into an integrated environment using object oriented methodology to develop the interactive visual lean system.
- Run a real life case study to demonstrate the system.

The next section proposes a conceptual framework and describes the different modules for earthwork projects and their functionalities.

DEVELOPMENT OF AN INTERACTIVE VISUAL LEAN SYSTEM

The system integrates the different earthwork modules which include: resource module, profile visualisation, optimal distance calculation, activity planning and scheduling in an object oriented environment. Figure 1 presents a conceptual framework for the developed system. It describes the input data structure, system processes and outcomes of the system. The input information describes empirical data that was collected from many different sites in order to calculate the possible accurate productivity of resources. The system process presents an integration of above mentioned earthwork modules to exchange the information between different component for earthwork operations, productivity rate calculation, activity planning and scheduling processes. It aids the project planners to manage the site operations efficiently and accurately by avoiding an unnecessary execution of resources in order to reduce waste at operational phase. Earthwork operations have predefined resources and their duration is calculated through productivity rates. The system demonstrates an interactive profile viewer for "Mass-haul" and "Time-distance" profiles, resource model for productivities calculation, Gantt viewer for activity planning and management. The system demonstrates adoption of the lean principles such as:

- **Specifying the value** (empirical data from site experiences) – It collects the equipment data from number of site experiences. It specifies the empirical data of resources such as equipment type, site constraints, and external factors among others. It inputs the real-time data of earthwork profiles.
- **Map the value stream** (Develop Atomic model) – It develops a number of atomic models. It reduces the complexity of the resources by creating an

atomic model mechanism that assists to avoid unnecessary allocation of resources in order to eliminate the waste of resources at operational phase.

- **Smooth flow of Information** (Integrating earthwork modules) - The model integrates different earthwork modules such as Earthwork views, resource configuration and project planning management in order to exchange information smoothly between different earthwork components.
- **Pull approach** (customise productivity rates and project planning)- The system can focus and customise productivity rates by managing atomic models and activities planning. It improves the resource planning by allocating resource as per project requirements at specific time.
- **Pursue perfection** (applying above all + transparent interactive knowledge driven model) − Combine all of the previous improvements that develop transparent knowledge driven model for continuous improvement in order to reduce wastes at operational phase.

This simplifies the working procedure substantially, especially in performing what-if analyses. Section 2.1 to 2.4 describes the various earthwork modules in details.
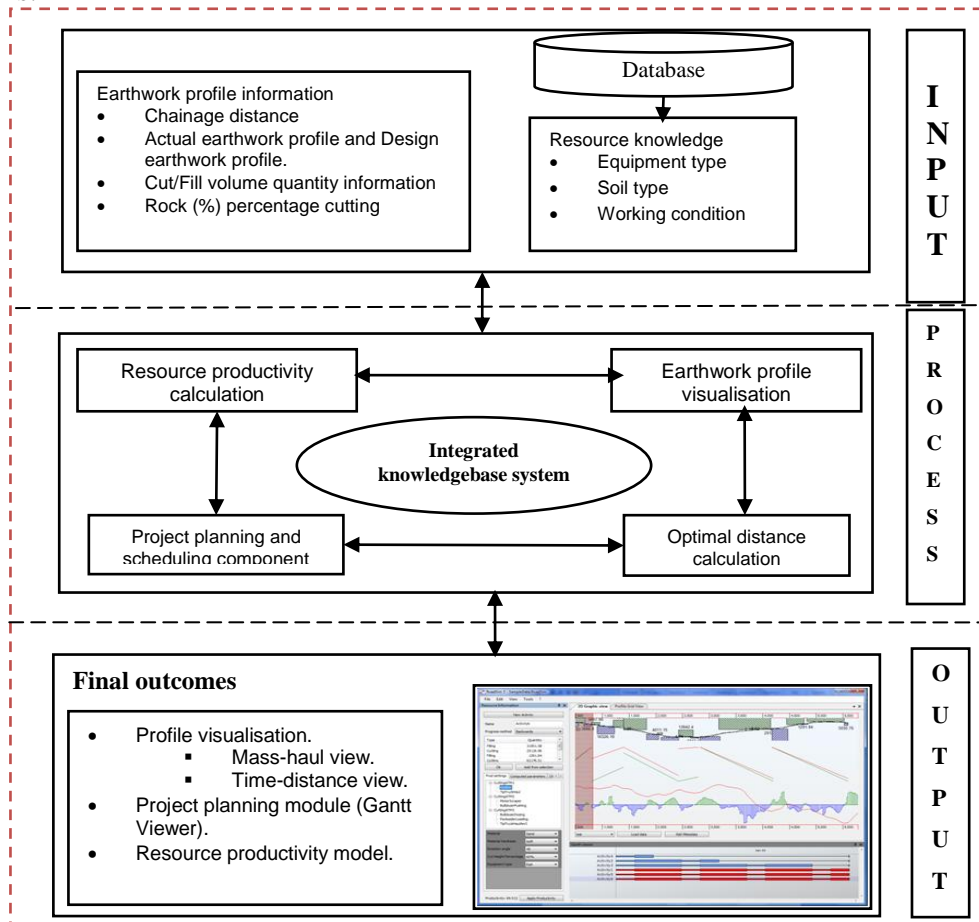

Figure 1 : System framework

INPUT OF THE SYSTEM

There are two types of system inputs: **I)** Resource knowledgebase database **II)** Earthwork profile data. Resource module stores site experience knowledge of equipment data to carry out different earthwork operations such as cutting/filling on construction sites. It specifies the empirical values of resources such as soil type, equipment type, resource efficiency and haul distance. The user should input earthwork profiles into the system prototype that store input data such as chainage distance, volume quantities, actual and design ground level. Sections below elaborate on the atomic models for different set of resource model calculation.

Atomic Models

An atomic model refers to the involvement of the number of equipment units which can be used to perform an activity, such as cutting or filling, in earthwork operations. In order to reduce the complexity of earthwork operations, atomic models are divided into the set of equipments. Each model has a different set of equipment to carry out different earthwork activities. Atomic models use empirical information augmented by interviews and knowledge elicitation from construction managers (Castro and Dawood, 2005). It maps the value stream to avoid unnecessary execution of resources and reduce resource waste during the execution phase. It assists project planner to carry out different "What if-Scenarios" to facilitate the choice of resource selections as per project demands. Examples of atomic models presented in figure 2 are given below:

    Excavation operation - Excavate the soil mass using Excavation equipment.

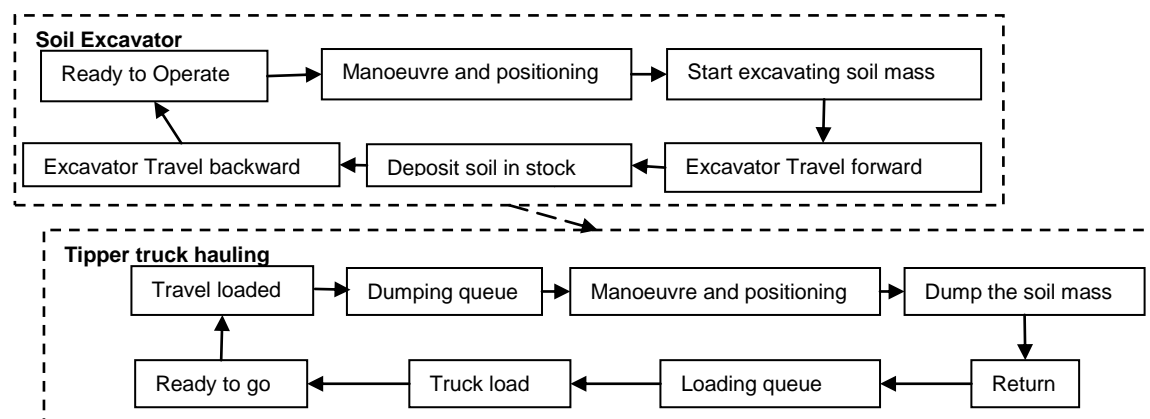   ***Tipper truck Hauling-*** Haul the excavated soil to a specific distance using tipper truck.

Figure 2 : Atomic model for Cutting operation

SYSTEM PROCESS

The system process presents an integration of various earthwork modules: Profile visualisation, Resource productivity calculation, Optimal distance calculation and Project resource planning for earthwork operations on construction sites.

Profile Visualisation

This is an interactive earthwork visualisation component. This component visually manages the resource information for planning the earthwork operations. It visualises

customized earthwork profile information into mass-haul and time-distance visualisation profile. The user should input earthwork profile data to be able to visualise this information into graphical as well as tabular format. There are two types of representation for earthwork profiles: **I)** Mass-haul profile: It visualises cutting and filling volume quantities along with Bruckner curve (Mass-curve). Planners can interactively select earthwork volume to calculate cutting/filling quantities and assign resources (team and equipment) on a specific chainage distance. **II**) Time-distance view profile: This presents an earthwork profile along a chainage distance versus activity progress direction and time. It demonstrates a specific activity (duration is presented in number of weeks) that will be carried out on a chainage distance. The system has a feature to demonstrate activity progress into "forward" and "backward" direction (Refer figure 3).
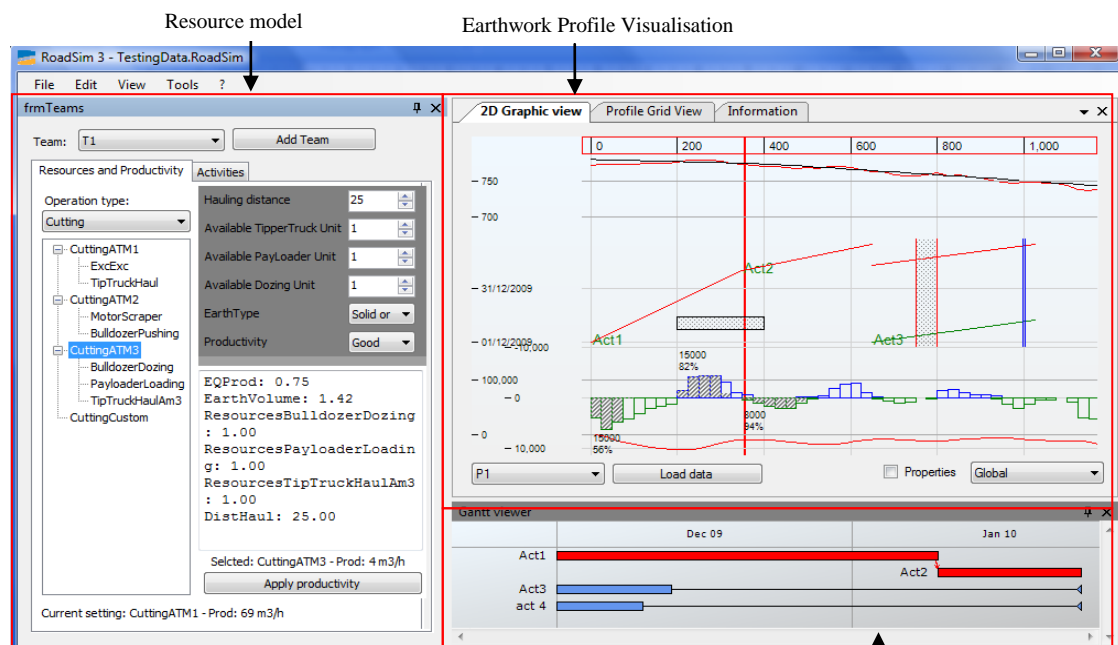

Figure 3 : Earthwork Components

Resource Productivity Calculation

The productivity formulas have considered all factors affecting the productivity including site working conditions, resources availability, site constraints and external factors. An equipment productivity calculation has been developed by RoadSIM (Dawood and Castro, 2009). The resource model specifies the atomic model level and resource level which adds the value during productivity calculation by eliminating the repetition of dependent value such as earthwork type, equipment efficiency among others in the resource model hierarchy (Refer figure 3).

Optimal Distance Computation

Mass-haul distance optimisation is achieved by linear optimisation technique. It minimises the waste and maximizes the utilization of resources by optimising the mass-haul movements that impacts on time and budget. It optimise the mass-haul movement along with consideration of borrow pit and land-fill section (form of waste). The simplex algorithm has been implemented to solve linear optimisation

problems in order to balance mass quantities and optimal distance. This algorithm has been developed in C#.Net by using LPSolve library (Open source).

Project Planning and Scheduling

The Gantt chart is a useful graphical representation technique to plan and schedule activities for complex earthwork projects. The "Gantt-viewer" assists planner to organize a list of weekly earthwork activities. It visualises the activities into Gantt chart format in order to analyse the sequence of operations. This module has a project management capability so that planners can change dates, predecessor and successor as required. It focuses on pull approach by allowing user planning customisation and necessary resource allocation. Activity duration depends upon the selection of the resources for mass-haulage. If the atomic model changes, productivity will change which affects the total activity duration. This is a very powerful project management engine that identifies the critical path of the earthwork projects (Refer figure 3).

OUTCOME OF THE SYSTEM

The system is a sophisticated, user-friendly and valuable tool for resource planning of earthwork operations. The system can be useful for planners to analyse various information such as earthwork operation volume quantities, time location planning etc by producing Mass-haul, Time distance, and Bruckner view (Mass-curve) diagrams. The interactive nature of the system aids the planner to select balanced volume quantities in order to plan different earthwork activities. The system also visualises road obstruction elements such as Bridges, Hydraulic passage, Entry access point, Upper and under passage etc.

The resource model simulates resource productivity calculation for project planner to carry out different "What if-Scenarios" in order to facilitate the choice of resource selections as per project demands. The system has a graphic "Gantt viewer" to analyse the different plan activities and visualises the sequences of planned activity operations. In overall this system verifies the integration of different earthwork modules and use of lean principles in order to improve quality, productivity and efficiency on road construction sites.

DEMONSTRATION OF PROCESS THROUGH REAL LIFE CASE STUDY

The real life site case study data is used to test the system prototype in order to verify the expected outcomes. The collected data of a 5.6 km length of road section in Portugal was used to demonstrate the developed prototype functionalities. As an input data, earthwork profile (Chainage distance, 25m intervals), Actual and Design ground level) and sectional volume profiles were considered to calculate the earthwork operations quantities. Below section presents a brief overview of system processes.

BRIEF OVERVIEW OF INTERACTIVE VISUAL LEAN SYSTEM PROCESSES

This section presents process of the developed prototype (Refer to figure 4). First, the system is started by the user, and then a new project file is created to store the project configuration for later use. The user must create and load earthwork profiles. Based on the loaded earthwork profiles, the system visualise volume quantities and generates Bruckner-curve (Mass-curve). The user creates a team that instantiate atomic model to

configure resource parameters such as site working conditions, equipment efficiency and external factors for earthwork operations and allocate resources.
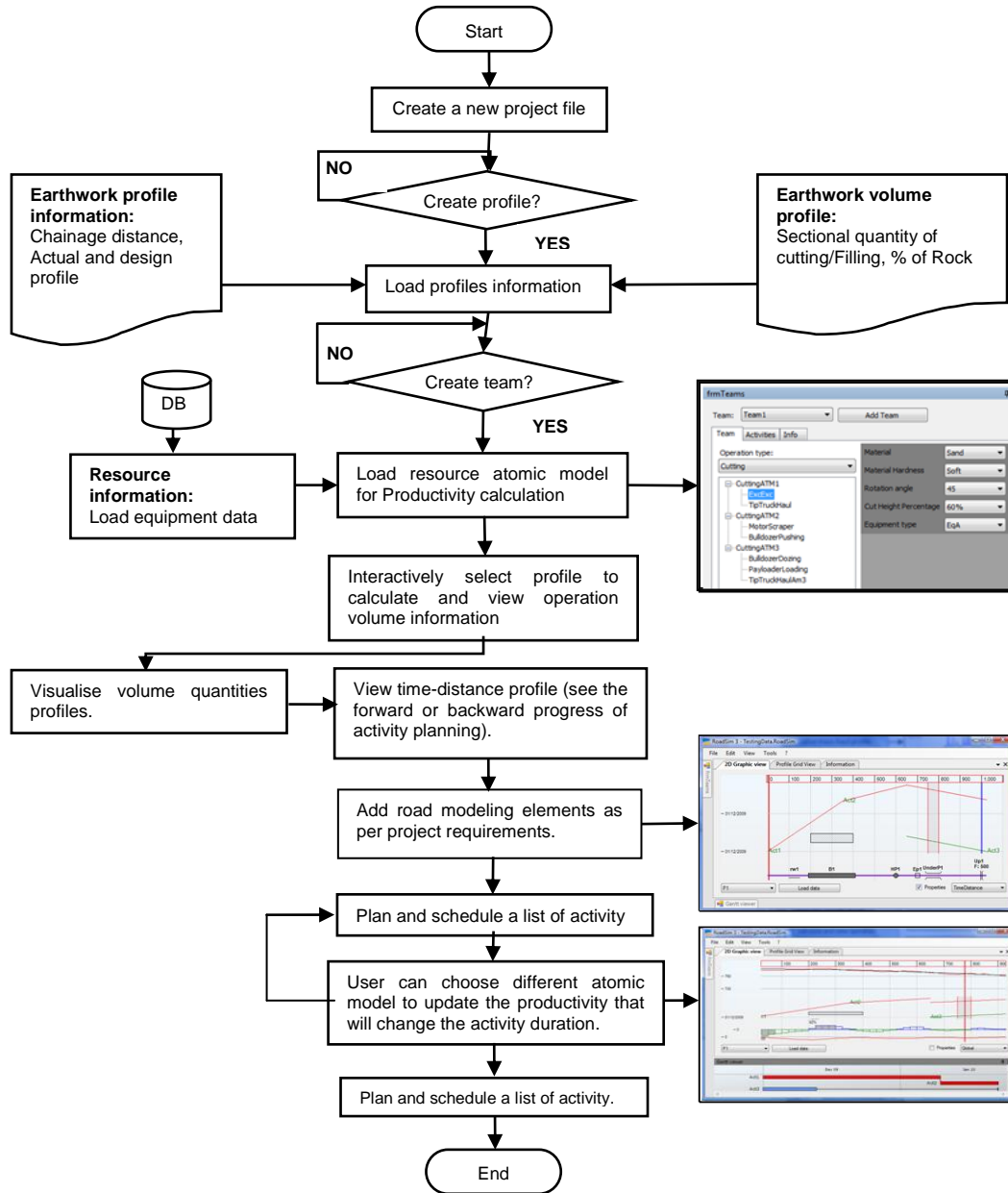

Figure 4 : Functional model of system prototype

The user can select the alternative atomic model to calculate volume quantities for the selected chainage distance area (Interactively users can select earthwork volume profiles on 2D graphic viewer modules). The atomic models selection and planning management modules enables continuous improvement during planning activities. The system visualises time-distance view to demonstrate working location against time duration. The gantt viewer calculates the activity duration based on the selected productivity rates. It demonstrates planned activities in a sequential order to analyse the resource planning information. The system can also add and visualise the obstruction information such as Bridges, Hydraulic passage. The functional model aids users to understand the flow of the system in order to plan resources efficiently.

The system assists project planners at the planning and execution stage of road projects in order to manage resources for earthwork operations.

CONCLUSION

This research paper presents an interactive visual lean system to mitigate the complexity of earthwork operations, improve resource planning processes and reduce waste at operational phase. A review of current practices indicated that poor resource planning, low productivity and complicated nature of the construction sites are the major problems in construction industries. Such problems could be tackled by the use of IT enabled lean approaches.

Considering practical limitations of existing practices, this research paper test the hypothesis by proposed interactive visual lean methodology to plan on site resources for earthwork operations. It integrates different earthwork modules including the Resource information module (atomic model, resource productivity calculation, team allocation), the project planning and earthwork visualisation components (Actual and design graph, chainage distance, mass-haul and time-distance view, bruckner curve, road obstruction). It demonstrates the exchange of information between different earthwork modules using lean principles such as specify value, map the value, smooth flow of information, pull approach and pursue perfections which enables user friendly system functionalities and transparent knowledge driven model. The lean principles enabled conceptual framework is proposed for an interactive lean system to identify important research components.

The system enables more interactivity and flexibility in terms of user interaction due to the customisable sophisticated user interface. The system provides more transparency to the planner by customising different views of earthwork profile such as mass-haul, time distance and planning various activities. The system is a valuable tool for construction planner to improve project efficiency and resource planning process in construction sites.

FUTURE WORK

The future work will include control modules in order to measure the project performance and track the progress of the projects. The proposed system can plan and schedule the construction projects using critical path method and will apply lean enabled principles to schedule the projects for 4-6 weeks ahead in order to do short-term planning. The developed system will verify and validate a proposed hypothesis through a real life case study in order to confirm the practicality of the system in the real time road construction projects. In a further development knowledge base H&S rule and workspace conflicts can be integrated into project planning to do further development.

ACKNOWLEDGMENTS

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