AUTOMATIC GENERATION AND VISUALIZATION OF LOCATION-BASED SCHEDULING

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ABSTRACT: *Accurate and visual information of working locations is vital for efficient resource planning and location-based scheduling of earthworks, which is missing in existing linear schedules. Thus, construction managers have to depend on subjective decisions for resources allocation and progress monitoring from location aspects. This has caused uncertainties in planning and scheduling, and consequently delays and cost overruns of projects. A framework of prototype model was developed using the theory of location-based planning to overcome the above issues. This paper focuses on a case study experiments to demonstrate the functions of the model, which includes automatic generation of location-based earthwork schedules and visualization of cut-fill locations on a weekly basis. An arithmetic algorithm was developed by incorporating road design data, sectional quantities, variable productivity rates, unit cost and haulage distance. The model provides weekly information of locations, directions and cut-fill quantities of earthwork under different selections: construction sequences of cut/fill sections, site access points and equipment sets. The paper concludes that the model assists in identifying the correct locations and visualizing the space congestion during earthwork operations. Hence, project resources including heavy equipment and construction materials should be allocated more effectively and correctly from the location viewpoints and ultimately to improve site productivity and reduce production cost in linear projects.*

KEYWORDS: *Earthworks, Cut-fill quantity, Location-based scheduling, Productivity, Visualization*

1. INTRODUCTION

The construction industry has distinct characteristics in comparison with other industries in terms of one-off projects, site production, and temporary organization (Koskela, 2000). The planning and scheduling process of a construction project is a challenging task and the decisions taken in this stage have the foremost impact on the successful execution of a project from its early imaginary to the project completion stage (Ahmed and Walid, 2002). Planning and scheduling involve careful allocation of resources, along a linear construction projects at the required locations and when necessary throughout construction operations. Failure to decide on the optimum work activities with the required resources from location aspects have an adverse influence on project cost, time, space conflicts, and safety of site works in construction projects (Mawdesley, 2004).

Arditi et al. (2002) suggested that earthworks projects require a separate planning task for each project due to the distinctive characteristics of earthworks. The effective application of planning and scheduling techniques: such as CPM and PERT is limited, because the activities associated with linear construction projects such as roads, railways and pipelines are fundamentally different from building projects. Most of the activities in road projects are linear activities. A linear scheduling method has the potential to provide significant enhancement in terms of visual representation from the location aspects, and to progress monitoring because the method allows the project schedulers and construction managers to plan road construction projects visually and determine the controlling activity path and locations (Harmelink and Yamin, 2000). A new methodology with a computer-based model is introduced in this paper to overcome the above issues.

This paper presents a new methodology with a prototype model that generates automatically location-based

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schedules and provides a platform for visualising the scheduling information of earthworks from the location viewpoints, particularly in linear construction projects. The research devises a decision-support tool that aids construction managers in resource scheduling and progress monitoring more effectively, and assists in communicating the scheduling information from the location aspects throughout earthwork operations. In this paper, the location-base scheduling is dubbed as "time-location plan". The remainder of the paper outlines literature review, design a conceptual framework, and details of the prototype model development that includes inputs, processes and outputs. The key output of the model is automatic generation of location-based schedules (time-location plans) with optimised quantities of earthworks, particularly in linear projects. Finally, a case study experiments from a road construction project is illustrated.

2. LITERATURE REVIEW

Earthworks have unique characteristics and take place at the early stages of construction particularly, in linear construction project like road, railways and pipelines. They constitute a major component in road construction, absorb high costs, and there is a need to deal with haul distances for balancing cutting and filling quantities in a cost effective approach (Kim and Russel, 2003). For instance, a study of 145 road projects found that earthworks component was represented around 19.58 per cent of the monetary value of project (Castro, 2005). The earthworks activities also have direct effects in the sequencing of the rest of road activities since earthwork contributes higher percentage in project value. Decisions taken during the planning stage of earthwork operations have high impact on overall performance of the project (Mawdesley, 2004).

Mattila and Abraham (1998) stated that the subjective division of repetitive activities from location to location, the inability to schedule the continuity of resources and display the activity rates of progress, and failure to provide any information of performed work on a project site are key limitations of CPM. Mawdesley et al. (2004) pointed out that CPM networks are more suitable for large complex projects, however, line of balance and linear scheduling methods are more practical for the repetitive and linear construction projects. A linear schedule is used to reduce the interruption of continuous or repetitive activities, to maintain resource continuity, and to determine locations of the activities on any given day from the schedule.

Arditi et al. (2001) suggested that the line of balance technique is an example of linear scheduling method. This technique is based on the hypothesis that productivity for an activity is uniform. In other words, the production rate (productivity) of an activity is linear when time is plotted on the vertical axis, and location of an activity on the horizontal axis (or vice versa). The production rate of an activity is the slope of the production line, and is expressed in terms of units/linear meter per time. Scheduling methods such as line of balance, repetitive scheduling method, time-location matrix model, time-space scheduling method, linear scheduling methods, time-distance diagram and linear-balance diagram are known as 'location-based scheduling'. These methods are based on the theory of location-based planning in the management of construction projects (Kenley and Seppanen, 2009 and 2010). This method is important because it provides vital information of working locations throughout the earthwork operations, with the aim of reducing the dependency on the subjective decisions. The correct working locations and timing assist construction managers and planners in resource planning, mobilisation of heavy equipment at require locations and controlling site progress more effectively from location aspects. The linear scheduling methods, however, do not provide exact information of working locations and time throughout the earthwork construction.

Kenley and Seppanen (2009) pointed out that there are mainly two types of scheduling methodologies; an activity-based and a location-based methodology. The location-based methodology is also sub-divided into two types: unit-production and location-production scheduling. It is known as an alternative methodology, which is based on tracking the continuity of crews working on production tasks. DynaRoad (2006) developed commercial software for a construction schedule and controlling the earthwork activities in linear projects. This provides the location-based scheduling information for a whole section but lacks to provide weekly information of locations. TILOS, which is time-location planning software for managing linear construction projects, assist in visualising the repetitive tasks from location aspects. It also provides the flow of scheduling data in terms of time and location on a construction plan (TILOS, 2009). However, existing time-distance charts, produced by DynaRoad and TILOS do not provide weekly information of locations.

This is imperative for effective planning of resources and reducing the space conflicts at construction sites. Consequently, construction mangers depend on the subjective decision for earthwork scheduling due to the limited information of the working locations. Taking into account previous studies, it is concluded that location-based scheduling, which is based on the theory of location-based methodology, is an effective way of representing the planning and scheduling information of earthwork activities in road projects. From the reviewed literature, it was established that the existing time-distance chart is incapable of providing scheduling information of locations. Therefore, this research examined a new methodology for the automatic generation of location-based scheduling that is capable of providing the weekly or daily location information of earthworks. The next section discusses a framework of a computer-based prototype.

3. FRAMEWORK OF A PROTOTYPE

A general specification of the framework of prototype is outlined in (Figure 1) taking into account of the findings from the literature and industry review by (Shah and Dawood, 2011). The framework was designed by integrating the road design data, sectional quantities, productivity rates and unit cost of cut/fill sections and arithmetic algorithms in order to generate automatically a location-based schedule of earthwork and visualise the weekly scheduling information from the location aspects. The developed framework has the capability of generating terrain modelling, cut/fill optimisation, weekly progress profiles, and time space plan, cost profiles and cost S-curves of earthwork activities.

This research, however, focused on the experiments with different scenarios at construction site. A case study from road projects, using the developed algorithm in the prototype (Shah et al., 2008) for the automatic generation of location-based schedules of earthworks was utilised. The paper outlines a methodology that aimed to provide the correct information of weekly locations in the cutting and filing activities, particularly in linear projects like roads and railways construction projects. Although the prototype model is capable of generating weekly progress profiles, cost profiles and S-curve, this paper discuss the details of the methodology and algorithms which aids to automatically generate location-based schedules for earthworks and demonstrates of the function with a case study in a road project. The comprehensive explanation of the model component: inputs, processes and outputs are discussed in the next sections.

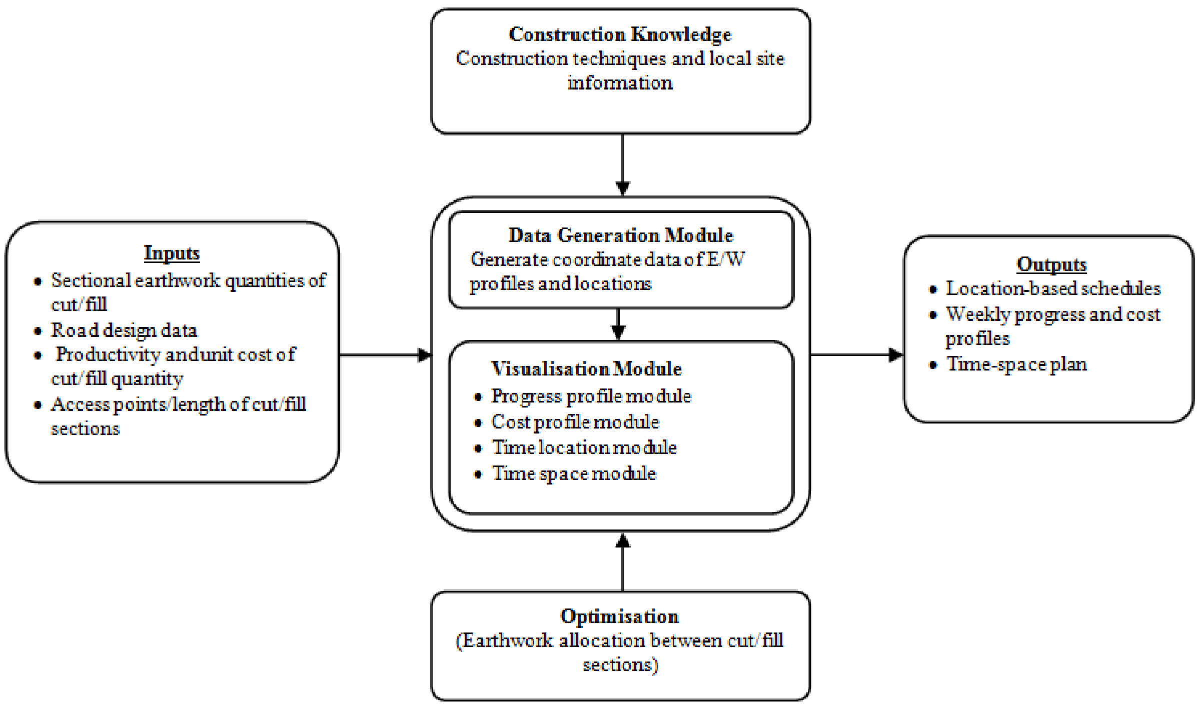

Fig. 1: Framework of a prototype

3.1 Prototype model

This section describes the key components of the prototype model, which includes automatic generation and visualization of location-based earthwork's scheduling information. The sectional quantities of cutting or filling activities, productivity and construction site knowledge base are inputs of the model. The cutting or filling quantity at each station is calculated using road design data including longitudinal section and cross sections. The productivity rate produced by the "RoadSim" simulator is integrated into the model as a main input. The soil characteristics, types of available equipment sets, haulage distance of soil, access road conditions and working efficiency of crew were incorporated within the "RoadSim" simulator. However, earthwork for rock excavation is excluded from this study since the nature of rock excavation is fully different than the normal earthwork operations. The construction knowledge encapsulated from planners and managers was utilized to select the right construction methods under different terrain conditions and soil characteristics considering the available equipment sets for earthworks. The site operational rules and knowledge allow in establishing the sequential relationships amongst listed work activities during the construction operations. The knowledge and operational rules were incorporated within algorithm for the generation of a location-based schedule.

Moreover, an optimization algorithm was also developed and integrated with the model for optimum allocation of earthworks and the movement direction between cuts and fills, borrows to fills or cut to landfills considering economical haulage unit costs. The optimization algorithm is designed by integrating the characteristics of mass haul diagram, unit cost simulated by "RoadSim" simulator, and Excel solver. The solver was built within MS Excel using a Simplex algorithm for linear optimization problems. Before producing a location-base schedule, it is vital to identify the possible sources and destinations of earthwork quantities required for filling and cutting operations in linear projects. The prototype includes four modules as processes: data generation module, visualization module, cost profile module and a time-location module. Data generation module processes the input data to generate the coordinate data of weekly locations of cutting and filling activities incorporating the different productivity rates. The time location module processes the coordinate data and generates location-based schedules for earthwork activities. The next section discusses the generation of location-based scheduling.

3.2 Generation of location-based scheduling

Location-based scheduling is a planning tool, which is widely applicable in earthwork planning tasks. The location-based scheduling is also known as time-distance planning, time-chainage planning and linear scheduling method. It enables the design and display of planning and scheduling information of earthwork activities in two dimensions: Location in X-axis and Time in Y-axis or vice versa together with topographical information of a road project. The slope of activities displayed in time location chart represents a rate of production of the earthwork activities. If the slopes of planned activities are compared with the slope of actual activities, they provide visual information of early indication regarding possible of conflicts or overlap between activities during the course of activity progress.

The proposed innovative methodology is capable to identify the starting and ending location as well as start and end period of cutting and filling activities at planning stage and the actual information of weekly locations assist to planners for efficient resources planning. The methodology is designed with an arithmetical algorithm that identify the locations (stations) along a road section which are broken down into weekly or daily schedules satisfying the linearity characteristics (start and end locations having equal production rate) of the earthwork activities. The equation 7 developed by Shah et al., 2008, is being used for identification of station number at each layer during earthwork operations by incorporating the 'variable' productivity data.

$$V_r = [\{\sum_{i=1}^{i=n} (V_i) - P\}/n] \qquad (7)$$

This process is repeated at each layer of cutting or filling sections to achieve the remaining volume (Vr) at each station is equivalent to zero (at the design level of road) at the selected working sections along a road project. At each layer, the starting and ending stations are identified and their lengths between the two stations are determined by the algorithm, designed in the model with help of VBA programming language. These lengths, at each layer between working stations, increase from the first to the last layer at both cutting and filling sections of the earthwork operation. Similarly, cutting and filling sections are selected according to the earthwork schedule to complete the earthwork operations throughout the construction of a road section. If the cutting or filling sections are longer, these sections are divided into manageable sections and the processes above are repeated to achieve the design level of the road.

In this model, two input variables: Productivity (P) of earthwork activities produced by “RoadSim” and working length (X) determined by “mass haul diagram” were integrated with the model to search the coordinate of starting and ending locations of working section. The algorithm assists to calculate the coordinate of working locations considering “variable” productivity data throughout the construction operations in a road project. Therefore, coordinates of weekly or daily locations directly depends on the value and unit of productivity i.e. weekly or daily productivity by assuming 40 hours per week or 8 hours per day as standard working time. The identified coordinate data of locations and time of earthwork activities are stored in a table at first and then exported the coordinate data by programme to generate location-based scheduling. The location-based scheduling has generated automatically. The automatic generated location-based schedule, which is key outputs of the model, provides more accurate information of working locations for earthwork scheduling on a weekly and daily basis. The location-based schedule assists to planners and construction managers in allowing the visualisation and analysis of the status of construction activities on a particular location along the road sections. The next section describes the visual function of the model that assist to planning in visualising the information about weekly locations and space congestion in earthwork operations.

3.3 Visualization of scheduling information

This section presents the development of a visualization component of the prototype model. This provides the visual information of earthwork scheduling, space congestion, progress profiles, and communicates the construction process sequences with consideration given to location aspects. The Visualization Module (VM) processes the coordinate data of location-based schedules and transforms them into a visual format to visualize earthwork scheduling information. The VM was developed using the C# and VBA programming language on MS Excel platform. The required input data was stored in MS Excel worksheets and used as database. Several VBA macros were developed to process input data and generate automatically into visual outputs of the model. The VM imports data using Structured Query Language (SQL) inquiry, and transforms the imported data into a visual representation in tabular and graphical information.

A snapshot of the visual outputs of the model is shown in (Figure 2), which includes weekly progress and cost profiles, cost S-curve, location-based earthwork scheduling information and time-space congestion plan. The location-based plan provides information related to the congested locations and pavement activities such as sub-base, base course and top surfacing tasks (see Figure 2). The visualization component also provides tabular information of starting and ending locations on weekly basis throughout the construction operations of earthworks and pavement. The following section describes a case study experiment to evaluate the model’s functions (automatic generation and visualization of location-bases scheduling information of earthworks) using a real life data from road project.

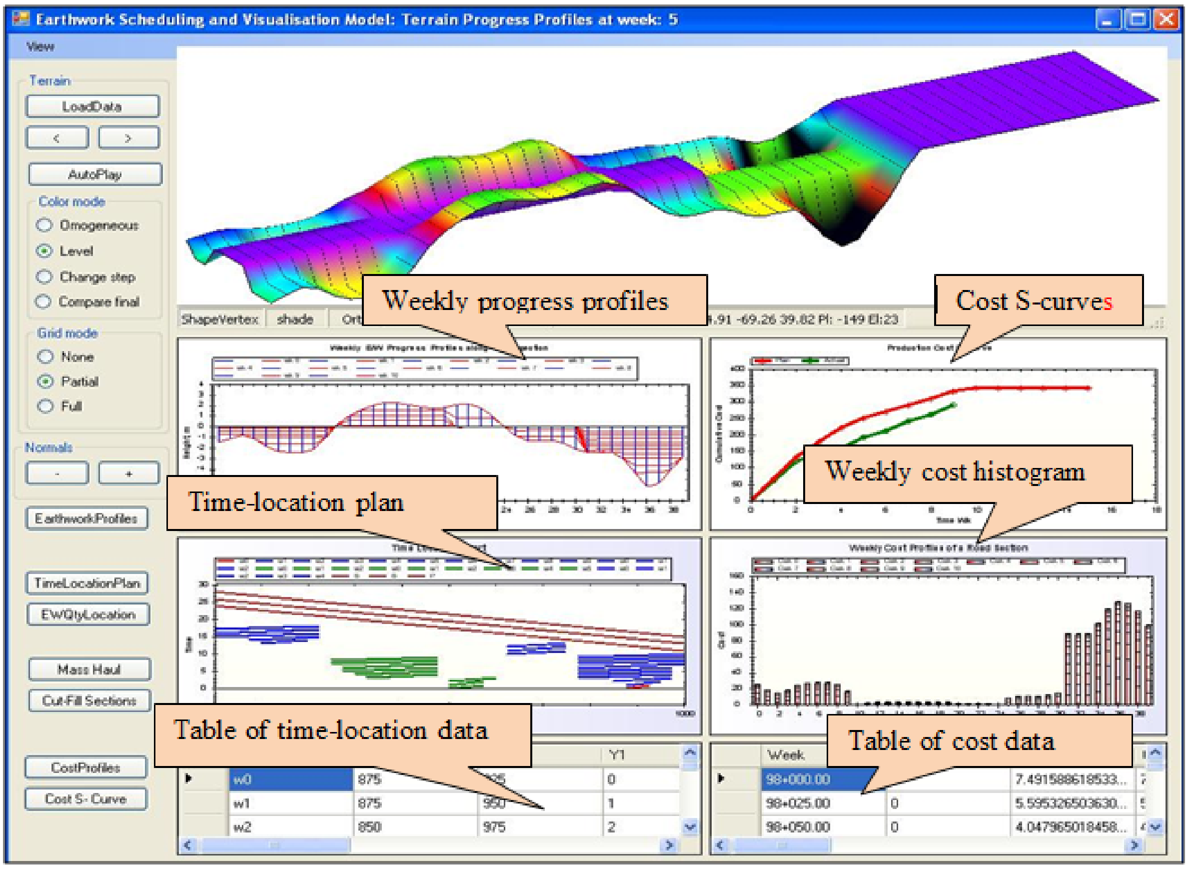

Fig. 2: Snapshot of the visual outputs of the model

4. A CASE STUDY EXPERIMENT

A case study involving 1.0 kilometer of road section of lot no. 3 road project in Portugal was selected to demonstrate the functionalities of the model. Actual road design data including L-section and X-section is considered, and the sectional quantity of earthwork is calculated assuming typical trapezoidal section at 25 meter intervals along the selected road section. The productivity data of cutting or filling activities is considered as a key factor that affects the construction duration, working locations and numbers of construction layers required to complete earthwork operations. Since the model outputs directly depend on the accuracy of the productivity data, the case study was run to compare the variation in the productivity value between actual site progress and model used value for earthwork activity. The case study results revealed that the actual productivity value was lower by 2 percent compare to the productivity value produced by the model to generate a location-based schedule for earthwork activity in road projects. The outputs of the model are: automatic generation of earthwork progress profiles, 4D terrain surfaces, cost profile, production S-curve and location-based schedules for earthwork planning and visualisation of scheduling information from the location aspects.

4.1 Experiments under different options in a road section

A road section having 4-cut and 5-fill sections was selected as a case study to demonstrate the model functionality of automatic generation of location-based schedules /time-location plans considering different site conditions, site access points and with construction sequences. The time-location plans produced by the model are presented below. A total of 18 weeks was required to complete earthwork operations for the selected road section when one equipment set for both cut and fill sections was mobilised assuming with a production rate of 6671 m^3/wk considering the 30 hrs per week as working time. The productivity was calculated using “RoadSim” simulator (Castro and Dawood, 2009), assuming a suitable set of equipment, soil characteristics and site constraints for the selected road section in the case study. A total of 7 different options considering under different site conditions and construction sequences were included in the experiment aimed with to evaluate the model function of automatic generation of location-based earthwork schedules or time-location plans.

4.1.1 Option 1: Construction sequences (C1-C4 and F1-F5)

In this option, the construction sequences of cut and fill sections were selected from C1 to C4 and F1 to F5 as shown in Figure 3. The earthwork operations included fill from cut with one set of cutting and filling construction equipment. The construction operation was performed from the start to finish stations in the forward direction. The direction of earthwork quantities (m^3) allocation between cut and fill section is shown in road profile with arrow diagram and the construction sequences of cut-fill operations are shown in time-location plan (Figure 4). Similarly, other options (2 to 7) are considered under different construction sequences between cut-fill sections including borrow pits for a selected road section.

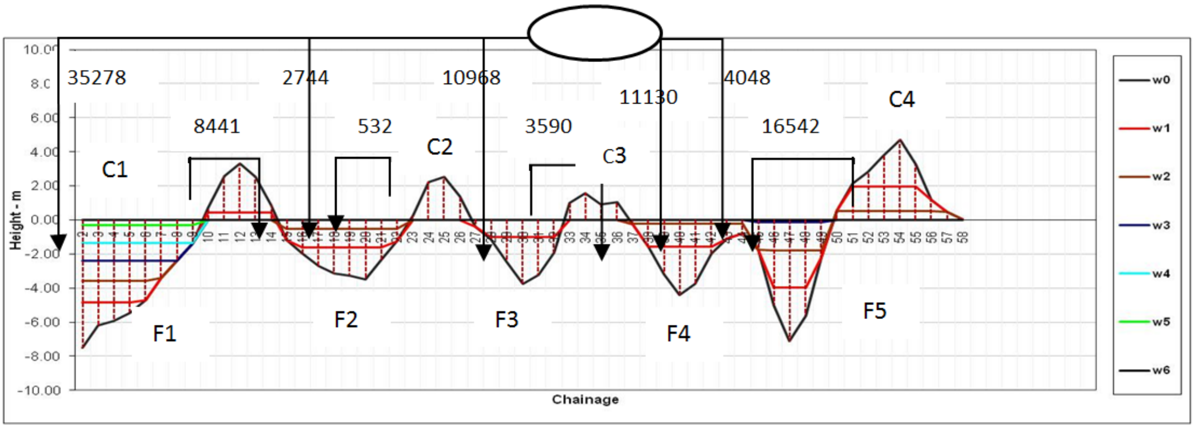

Fig. 3: Road section showing 4-cut and 5-fill sections with optimised earthwork quantities

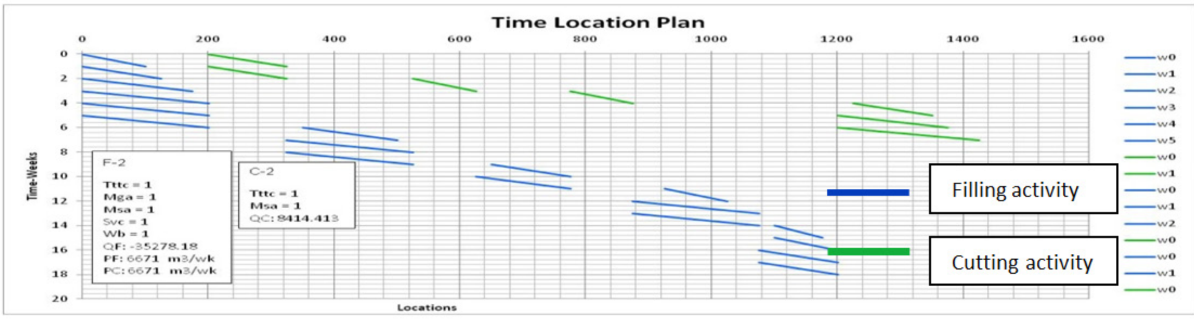

Fig. 4: Time-location plan of a road section generated by the prototype with option-1

4.1.2 Option 2: Construction sequences (C4-C2 and F5-F1)

In this option, the construction sequences of the cut and fill sections shown in Figure 3 above were selected starting from C4 to C1 and F5 to F1 with one set of construction equipment. The construction operations were performed from finish to start in a backward direction. The time-location plan generated by the model considering option 2 is shown in Figure 5.

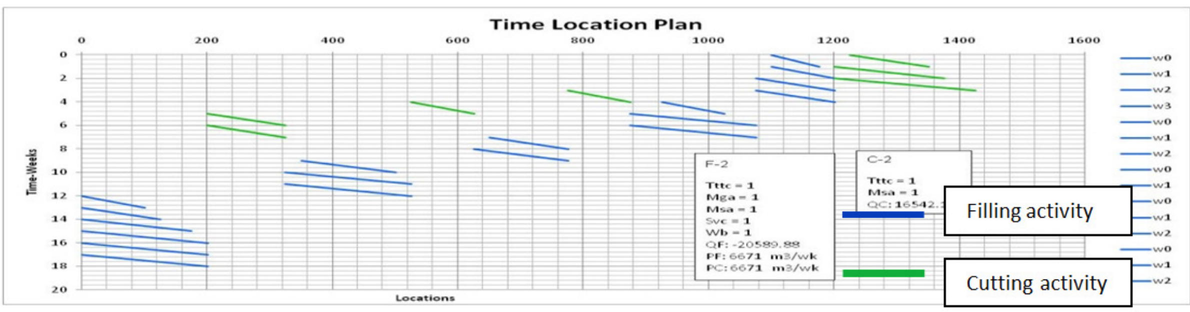

Fig. 5: Time-location plan generated by the prototype model with option 2

4.1.3 Option 3: Construction sequences (C4-C1 and F1-F5)

In this option, the construction sequences of the cut and fill sections shown in Figure 3 were selected from C4 to C1 and from F1 to F5 with one set of construction equipment. The cutting operation was performed from finish to start of a road section in the backward direction and filing operations starts from start to end in the forward direction. The time-location plan generated by the model considering option 3 is shown in Figure 6.

Fig. 6: Time-location plan generated by the prototype model with option 3

4.1.4 Option 4: Construction sequences (C1-C4 and F5-F1)

In this option, the construction sequences of cut and fill sections shown in Figure 3 were selected from C4 to C1 and F1 to F5 with one set of construction equipment. The cutting operation performs from start to finish in the forward direction and filing operations starts from finish to start backward direction. The time-location plan generated by the model considering option 4 is shown in Figure 7.

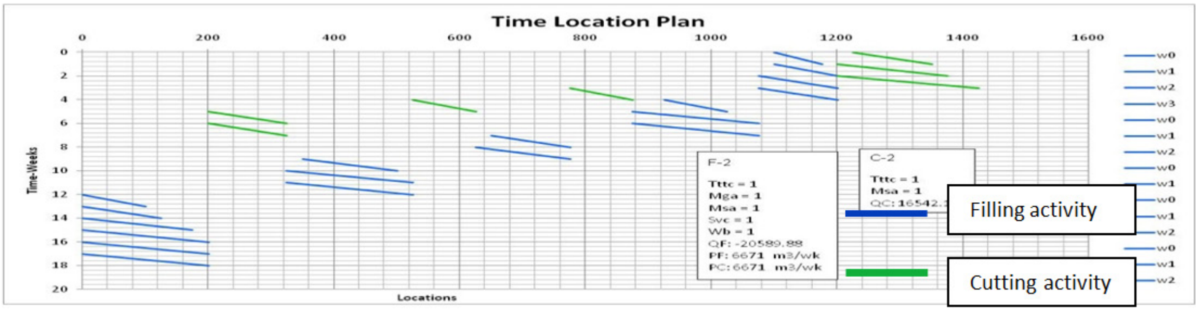

Fig. 7: Time location plan generated by the prototype model with option 4

4.1.5 Option 5: Considering obstruction at point A (at chainage 0+625)

In this option, the construction sequences of cut and fill sections shown in Figure 3 were selected from C1 to C4 and from F1 to F5 with two set of construction equipment. One set of equipment at the start of the road section and second set is at station (0+625m) due to an obstruction at point A. The time-location plan generated by the model considering option 5 is shown in Figure 8.

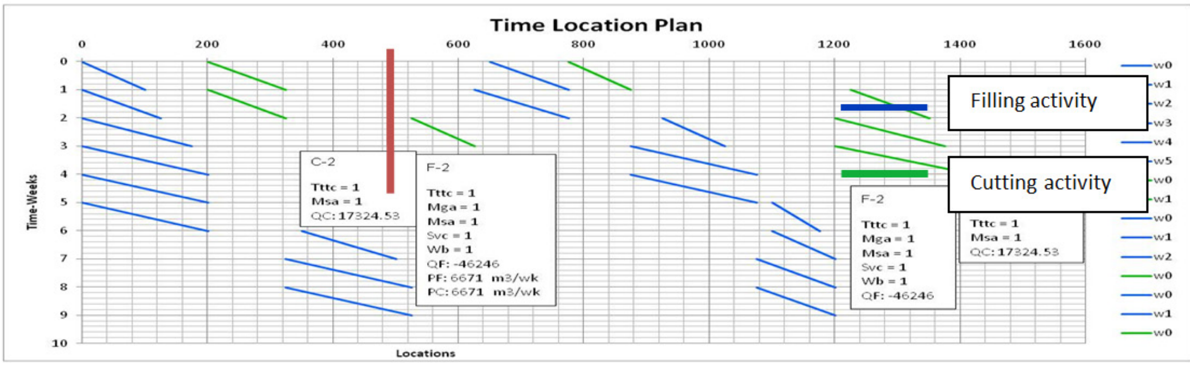

Fig. 8: Time-location plan generated by the prototype model with option 5

4.1.6 Option 6: Time location with daily productivity (1779 m^3/day)

In this option, the construction sequences of the cut and fill sections were selected from C1 to C4 and from F1 to F5 with two sets of equipment but the time location plan was generated on a daily basis. The time-location plan produced by the model under option 6 is shown in Figure 9. The time location plan showed a total duration of 30days @ 1779 m^3/day with 8 hrs/day and two sets of equipment.

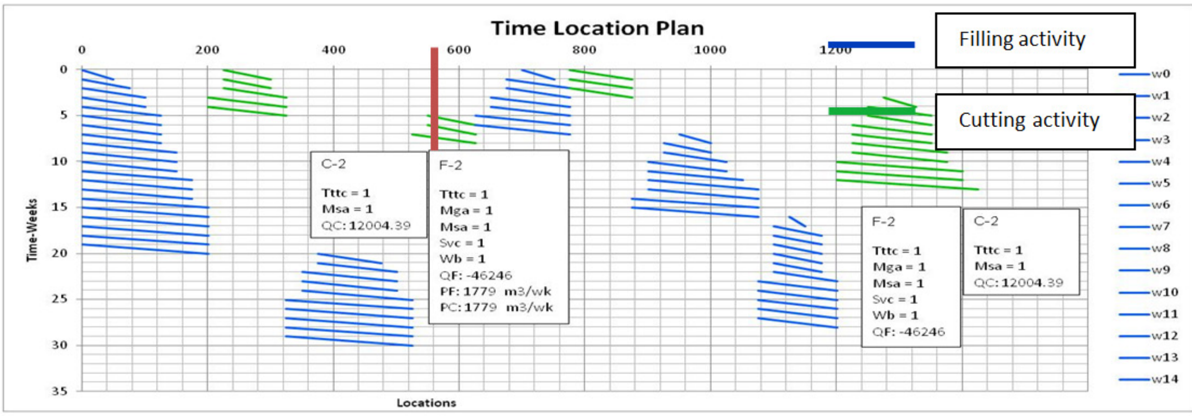

Fig. 9: Time-location plan generated by the prototype model with option 6

4.1.7 Optiom 7: Time-location plan with space congestion

In this option, the construction sequences of cut and fill sections were selected from C1 to C4 and from F1 to F5 with one set of equipment. The congestion location is shown in red in the plan at first week of fill section 5 only. The time-location/space congestion plan generated by model under option 7 is shown in Figure 10.

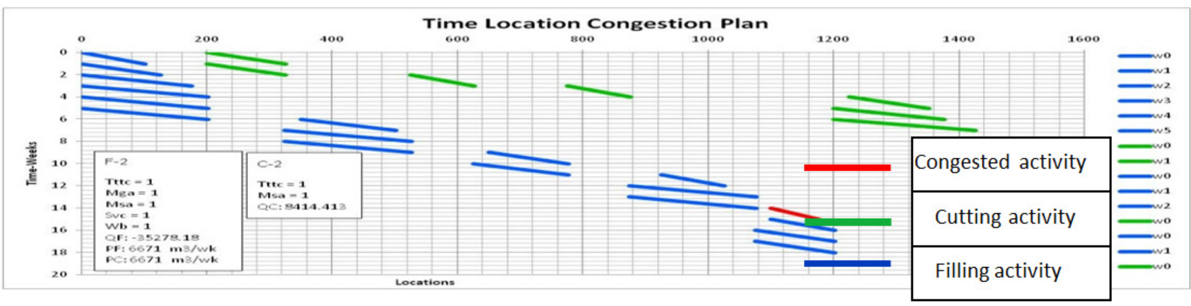

Fig. 10: Time-location congestion plan generated by the model under option 7

4.2 Comparison between company used and model generated location-based schedules

A 7 kilometre road section was selected with the assistance of a company (Mota-Engil) for the validation of the time–location plan (location-based scheduling) produced by prototype model. The duration of earthworks shown in a time–location plan provided by the company was compared with the duration shown in the time–location plan generated by the prototype model. The comparative results including detailed information of weekly working lengths/locations of a road section, earthwork quantities, productivity, and total duration of the earthworks are presented in Table 1.

Table 1: Comparison of between company-provided and model-generated time-location plan

S. N.	Road Chainage	Sectional Length (m)	E/W Quantity (m3)	Cut/Fill Activity	Production Rate m^3/wk	Company-produced Results		Model-generated Results		Variation
						Time (wk)	Locations	Time (wk)	Locations	Time %
1	0+000 -	925			2309		0+000		Table 1 of	
2	0+925 -	1750			3464		0+925 &		Table 2 of	
3	2+675 -	925			5196		2+675 &		Table 3 of	
4	3+600 -	3400			10392		3+600 &		Table 4 of	

The comparison results (presented in Table 1) show that model simulated production duration of earthworks is higher by 8.7 per cent (average) than the company estimated production duration of earthwork for both cutting and filling operations. The duration was calculated by rounding the values for each cut/fill section in case of the model-generated schedule, whereas, the duration was calculated by dividing whole quantities with productivity (production rate) of earthworks for each section in case of the company produced schedule (Table 1). Figure 11 represents a time-location plan/location-based schedule of a road project in Portugal, produced and utilised by the company. The plan was produced by dividing the road section into four sub-sections (0+000 to 0+925, 0+925 to 2+675, 2+675 to 3+600 and 3+600 to 7+000). Each section was planned with different sets of equipment separately at different production rates (Table 1).

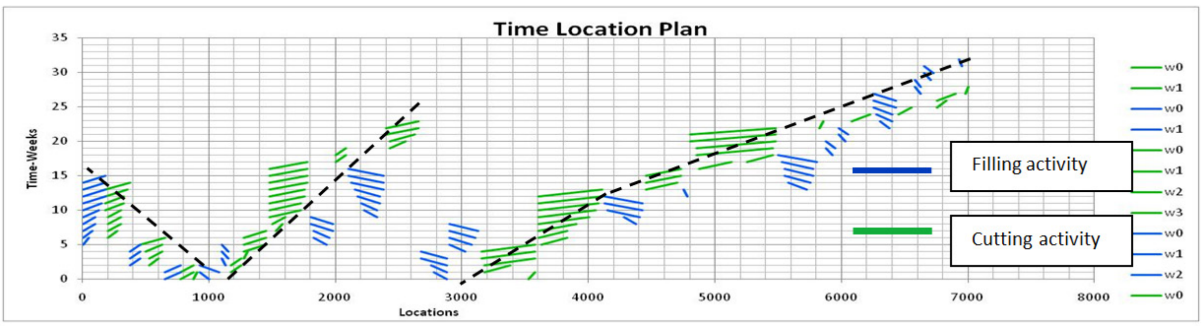

Fig. 11: Colour lines model generated and the dotted lines represent company-produced time-location plans

Additionally, several experiments were carried out at the earthwork construction site in a road project of lot no 5 in Portugal by Mota-Engil. The experiments revealed that the actual production time was 2.34 per cent lower than the model-simulated production time of earthworks because the delay in variation of soil characteristics at the cutting section. Hence, it was concluded the model produced location-based schedules that are widely acceptable for earthwork operations in road construction projects. Therefore, this should result in improved resource planning including mobilising construction equipment for earthworks from a location viewpoint.

5. CONCLUSIONS

The present study was designed to present a new methodology with a prototype model that generates automatically location-based schedules. One of the significant findings to emerge from this study is that existing linear schedules do not provide the correct information of weekly locations of work activities in linear projects. A framework and a prototype model with detailed specifications were developed by integrating different factors that affect linear schedule, such as the road design data, sectional quantities, productivity rates and unit cost of cut/fill sections and arithmetic algorithms. The algorithm, underpinned within the model assist to generate the weekly coordinates of working locations on a daily or weekly basis by incorporating different productivity rates and site constraints in earthworks. The model has capability to generate automatically weekly progress profiles, space congestion plan of earthwork operations in linear projects. A case study using data from road projects was used to demonstrate the functions of the model. An experiment was run to analyse the model generation capability of location–based earthwork schedules under different options of construction sequences and sets of construction equipment. These options include different sequences of cut-fill section in forward/backward directions, site access points, and different productivity rates. The experiment results revealed that the model provides weekly information of working locations and required resources including materials, equipment and crew in earthwork operations. The model was also evaluated from road construction experts and they suggested that it is a very useful tool in supporting the initial strategic decisions at the planning stage and provides the scheduling information more effectively from the location aspects. Running various strategies with the model would allow optimisation of resources, including construction equipment useful in the earthwork operations.

This study has found that the model-generated location-based schedules are satisfactory for practical applications as a location-based scheduling tool in earthwork operations in linear construction projects like roads or railways. The space congestion plan was also found as a valuable tool for decision-making in avoiding space congestion and the equipment being idle. The paper concluded that the model is a valuable decision support tool that assists construction manager in mobilising construction equipment and visualising scheduling information from locations aspects. The tool is also helpful in assisting the efficient resource scheduling, progress monitoring from location aspects, reducing space conflicts and communicating the scheduling information more effectively from the location aspects in earthworks construction.

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