

DEVELOPMENT OF INNOVATIVE VISUALISATION MODEL IN ROAD CONSTRUCTION

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ABSTRACT: Visualisation models have the potential to improve the management process of construction operations through a better understanding of what is needed to be built and when. In that context and in the drive for innovation in construction management, a framework aimed at the development of visualisation models of ground profiles for construction process has been conceived, designed and developed using road design data, construction site information and a RoadSim simulator. The sectional quantity of earthwork activity, which is generated by road design data, is the key input to the framework. The RoadSim simulator has been integrated with the framework to determine productivity and required equipment of a road activity where as the construction site information has been integrated to establish precedence relationships of tasks in order to develop a detailed schedule and visualisation models. In this paper, an innovative methodology is presented based on the derivation of a mathematical model for the automatic generation of ground profiles throughout the construction process. The developed models that is defined as Innovative Visualisation Models (IVM) will assist in communicating the construction scheduling information to project managers/planners through visual evaluation of road construction process in order to facilitate a logical schedule development and efficient decision-making process. The paper outlines and discusses the framework and demonstrates a small case study in a road construction project.

KEYWORDS: innovative methodology, visualisation models, detail schedules, road profiles, roadsim.

1 INTRODUCTION

Constructing a civil engineering infrastructure project of any magnitude has become more challenging due to the highly competitive environment and complexity of technology. Current practices in the construction industry suggested that road construction projects often overrun in budget and time due to change order of works, meteorological and environmental factors, and potential conflicts with stakeholders, social activities and a large number of unpredictable factors. In addition to these influencing factors, the continuously evolving construction methods and techniques stipulate the need for innovative tools that can assist project managers/planners to plan and manage construction projects more efficiently.

Construction scheduling is an important part of the project management process in a project and it has served as the fundamental basis for monitoring and controlling project activities. Although the use of the process has enhanced the performance of the construction team and helped them in executing projects more efficiently, studies have proven that a considerable amount of eight-hour day is non-productive time, especially due to “waiting” time (Adrian 1994). This “waiting” time is characterized by two types of events: work waiting for resources (labour, materials or equipment) or resources waiting for work. The majority of the non-productive time related to “waiting” can be associated with a lack of detailed construction planning and scheduling. The master scheduler

need to develop into a detailed schedule with a certain level of details depending on the complexity of the project and the intended user of schedule. Personnel involved in the execution stage of work needs a breakdown of master schedule into a detailed schedule that includes detailed information of daily production quantity and required resources to be performed, thereby enabling more effective planning and managing the day-to-day work tasks at the construction site. With visualisation model available, project planners can plan construction schedule more effectively by reducing non-productive time related to waiting.

The development of a visualisation model of road construction schedules is the main objective of the research undertaken, which is the second stage of the RoadSim simulator Project (Castro and Dawood, 2005). The RoadSim is a construction site knowledge-base driven construction simulation system used to develop a master schedule of road construction. RoadSim is based on the definition of the atomic models of construction activities and the respective inputs are Bill of Quantity (BOQ), required resources, haulage distance, and condition of access roads, soil characteristics, working conditions, and other relevant factors that are important to determine the major outputs: productivity and unit cost of road activity.

Various research studies have been conducted in building projects, in the area of construction scheduling and visualisation. Dawood and Mallasi (2006) formulated an in-

novative 4D space planning and visualisation tool that assist in critical space analysis and quantify the volume of components, materials/plant items being stored and used at construction site in relation to the space available, in order to identify the space congestion at work face using visualisation/simulation tools. Also, Mallasi and Dawood (2001) concluded that a congested workspace was a factor in decreasing the productivity at the workforce by 30%. Retik et. al. (1990) has explored the potential application of computer graphics to construction scheduling to represent the schedule of construction progress in terms of graphical images at any date. Kamat and Martinez (2001) have described a general purpose of visualisation system that is simulation and CAD software independent. This system enables spatially and chronologically accurate 3D visualization of modelled construction operations and the resulting products.

Visualisation models have been researched and utilized at the design stage but its use in construction planning is still limited, especially in infrastructure projects. Despite various research studies, it is clear that there is a big gap in road construction simulation and visualisation literature and this research study is expected to fill this gap. Studies related to road construction visualisation have been done in the past. Andrej, T., Branko, K. and Danijel, R. (1999) have introduced a new level of support to engineers throughout the product life cycle to producing an independent platform to deal with 3D visualisation and product modelling using roads as an example. Liapi (2003) has focused on the use of visualisation during construction of highway projects to facilitate collaborative decision making on construction scheduling and traffic planning, however, this research neglected the visualisation of the construction schedule for intermediate stage of construction process. Kang et. al. (2006) suggested an approach to simulate 4D models for the earthwork movement activity for the intermediate stage of the construction process in civil engineering projects using morphing techniques and the realisation of construction progress in graphical images. However the authors didn't address particularly detailed schedules of construction process.

In this paper, the research study focuses on innovative methodologies to automatically generate ground profiles for visual evaluation of construction schedule information including resources utilisation, location of activities that are under execution and construction methods throughout the construction process in order to facilitate a logical decision-making process in the construction scheduling and resources planning processes. The following section details the component of the framework.

2 METHODOLOGY

2.1 Framework of visualisation model

The framework for visualisation model is outlined in figure 1. The framework focuses on identifying innovative methodologies for the development of a visualisation model for automatic generation of road profiles. There are two key parts in the processing stage for development of the model: development of detailed schedules, development of visualisation model. At later stage of research

study, the framework will be optimised considering the key factors such as access points or location of site offices using search algorithms such as genetic algorithms.

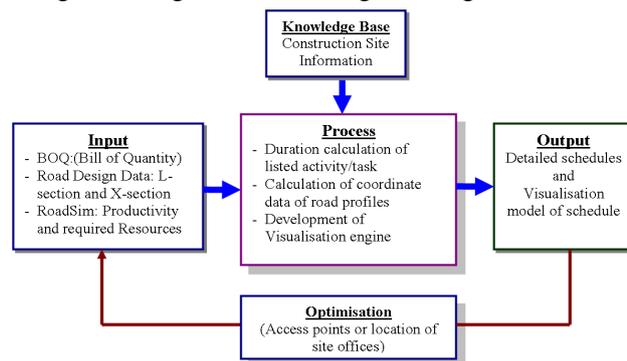


Figure 1. Framework specification of Innovative Visualisation Model (IVM).

2.2 Input

The main component of the framework is BOQ (bill of quantity) of selected activity of road projects. The road design data such as L-section & X-section, which helps to generate the sectional quantity at required interval of chainage and access points that dictate the start point of work, are other key inputs of the framework defined as the Innovative Visualisation Model (IVM). These inputs are incorporated with productivity produced by RoadSim Simulator in order to determine the duration of the road activities and the required resources. BOQ quantity and road design data assist in determining the sectional quantity of the road activities at each section of the required interval. Site survey information assists to identify the possible site access points where the construction operation starts and a possible route for transporting materials. The soil characteristic of the road section that controls the productivity was already incorporated within the RoadSim simulator. The site operational knowledge-base assists to establish sequences for the listed activities. The following section describes and indicates the process of a detailed schedule development including information flow.

2.3 Process

The flow chart of detailed schedule development presented in figure 2 shows the main activities and their logical interaction for the development of the model. The detailed description of schedule development and visualisation model for automatic generation of road profiles throughout construction process is given below:

2.3.1 Schedule development:

The list of locations along the road profile of the L-section is identified using the BOQ activity list. At this stage, site survey information and road design data of L-section & X-section have been used to identify the list of locations as per required interval and required accuracy. Similarly, possible start points and access routes for transportation of mass quantity from borrow pit or to spoil/dumping site have been identified using site survey information. The location of access points is a key factor that affects construction planning and visualisation models. The mass quantity is calculated

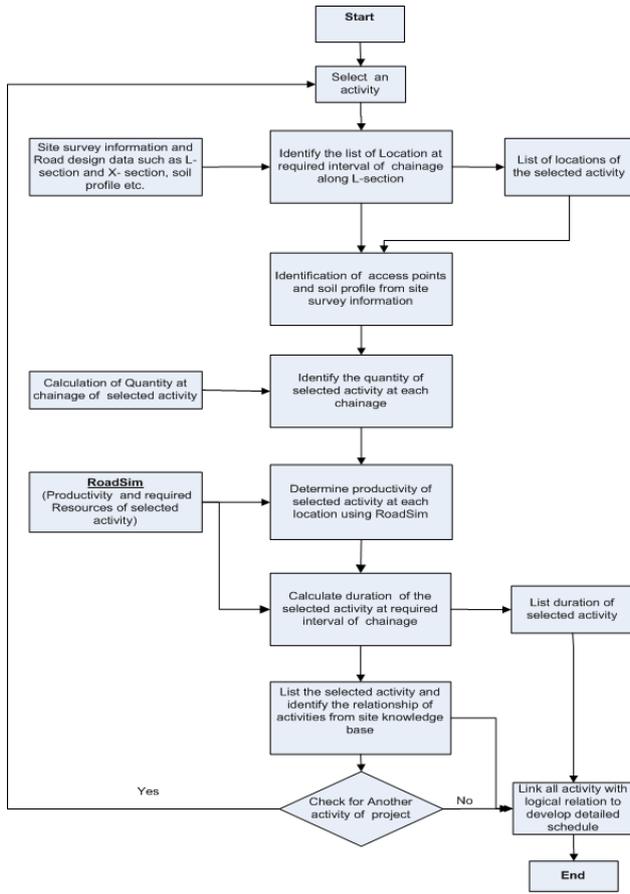


Figure 2. Information flow chart of detailed schedule development.

at each and every list of locations of the road project using civil 3D. The RoadSim is used to identify productivity information and required resources at selected locations and activities of the road building process. The productivity is used to determine the duration of the activity in BOQ. Similarly, the process will be repeated for other activities of road projects and the precedence relationship is established based on the construction operation knowledge-base.

2.3.2 Coordinate data calculation:

A mathematical formula has derived to determine progress of height for mass earthwork bases on assumption made below in this study. The mathematical model assists to determine the progress of work in terms of sectional height and the corresponding surfaces are displayed at the selected period of time. During the calculation of mass earthwork progress, firstly the remaining volume/per unit length at the selected location is determined in order to find the remaining height using a mathematical formula. In road construction, the typical cross-sectional as shown in figures 3 & 4 are applied and thus considered to formulate the mathematical model for that shapes as shown in case (a) & (b). There are other typical sections that are rarely used and are not considered in this paper. Following section describes about the development of the mathematical formula.

Case (a) Common typical road cross-section which is mostly used in road project has presented here for mathematical model analysis:

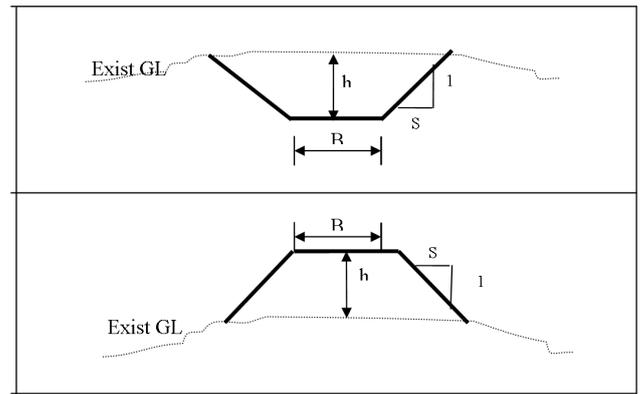


Figure 3. Typical cross-section for cutting and filling of road surfaces.

During the derivation of mathematical formula, following assumptions are made:

- Road cross-section is considered as trapezoidal shape having side slope S: 1.
- A_i = Cross-sectional area of trapezoidal at section i. = $Bh_i + Sh_i^2$
- i = number of section varies from (i = 1.....n) along the road.
- S: 1 = Horizontal: Vertical
- B = Design Width of Road
- h = Height between exiting ground level and design level at a road section.
- V_i = Volume of earthwork for Cut/Fill at section i
- L = length between two sections.

$$A_i = \frac{V_i}{L}$$

$$Sh_i^2 + Bh_i + \left(-\frac{V_i}{L}\right) = 0 \quad (1)$$

Since, this equation no 1 is a quadratic equation the height of the cross-section shown in figure 3 can be determined by equation no 2 as follows:

$$h_i = \frac{-B \pm \sqrt{B^2 + \frac{4SV_i}{L}}}{2S} \quad (2)$$

Case (b): Another type of typical road cross-section, which is often used in uneven terrain surface.

After the derivation of mathematical equation of area and volume for the section shown in figure 4 and comparison with quadratic equation, height of cross-section is calculated by the equation no 3 shows below:

$$h_i = -b \pm \left[\left(\frac{I}{SN} \right) \sqrt{\left(\frac{V_i S}{L} \right) \times \left(I - \frac{S^2}{N^2} \right)} \right] \quad (3)$$

Where:

- h_i = height of cross-section at section i
- i = number of section varies from (i = 1.....n) along the road.
- N = Transverse slope of existing ground Horizontal: Vertical (N: 1)
- S = Side slope of cross-section Horizontal: Vertical (S: 1)
- b = half width of road section.

- V_i = volume of mass earthwork Cut/Fill at cross-section i
- L = Length between two section.

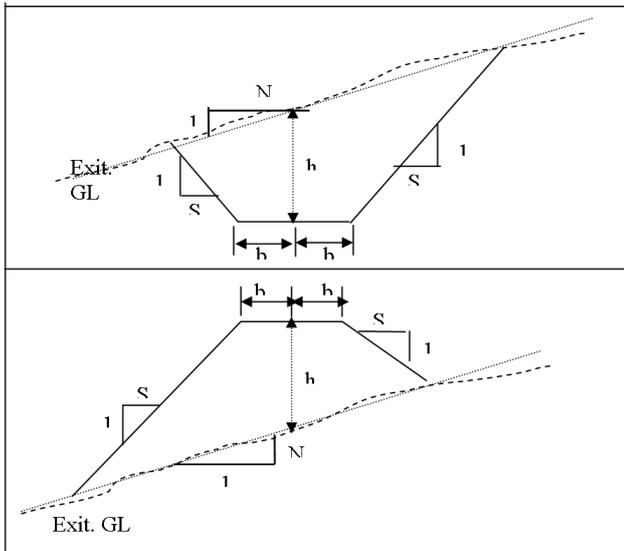


Figure 4. Typical section of road cross-section for irregular cutting terrain surface.

Illustration of example for calculation of height as Z-coordinate:

Data for illustration is selected from lot no 3 of road project in Portugal.

Assume at section (i) between chainage 0+025 ~0+050,
Volume (V_i) = - 2834.70 m³ (sign show the cutting and filling volume)

Side slopes S: 1 = 1.5:1

Width of Road (B) = 26.1 m

Chainage interval (L) = 25 m

As per equation no 3

$$Height(h_i) = \frac{-B \pm \sqrt{B^2 + \frac{4SV_i}{L}}}{2S}$$

In above equation, only positive sign is considered for most feasible value in this case.

$$h_i = -26.1 + \sqrt{(26.1)^2 + \frac{4 \cdot 1.5 \cdot 2834.70}{2 \cdot 1.5}}$$

$$h_i = -8.39$$

Here the negative value of height shows the height of filling quantity and positive value of height shows cutting quantity. The following section describes an initial case study for demonstration of the developed innovative visualisation model.

2.3.3 Development of visualisation model:

In order to generate the visualisation models of a construction operation in a road project, a typical earthwork activity including cut to fill / or spoil is proposed to develop the model and visualise the automatic generated road profiles. The quantity of selected activity has determined at every locations of the required interval. The du-

ration required to complete is calculated by using the production rate provided by the RoadSim simulator under assign set of equipment and characteristic of soil. The visualisation model is based on 3D (2D plus height) of terrain surface in order to develop the rendered visualisation model. The flow diagram of visualisation model and height calculation for different layer/weeks is shown in figure 5.

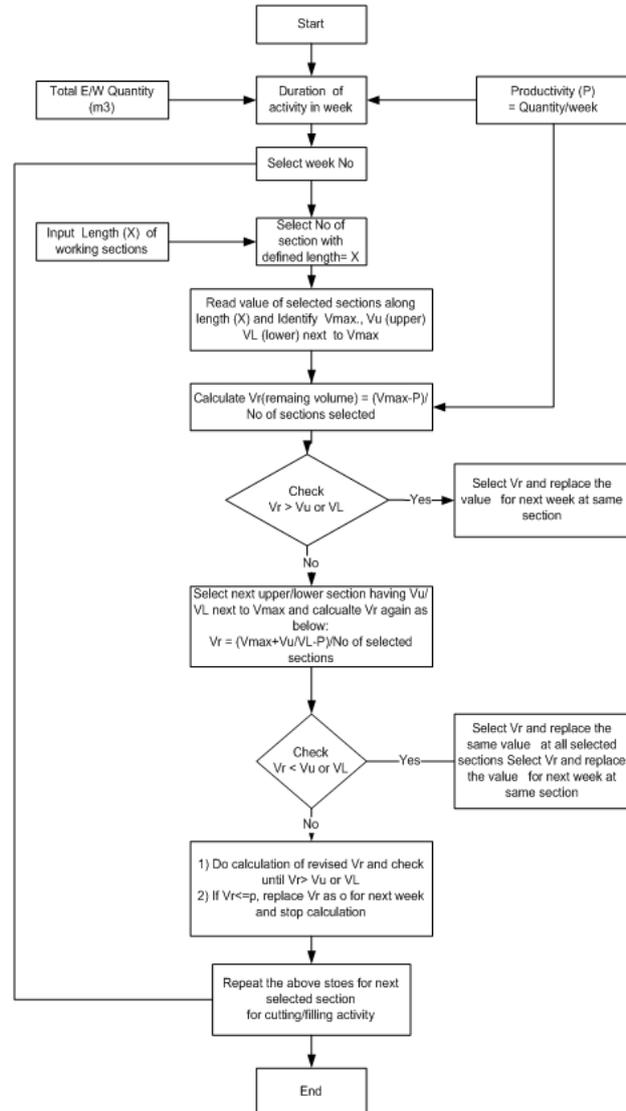


Figure 5. Flow diagram of visualisation model.

The visualisation engine has been developed using the programming language; visual C++ and Direct X. The input of the visualisation engine is coordinate data that is developed in excel sheet and saved as a text file based on innovative methodologies using mathematical model as described above. The x & y coordinate is considered as road length and width of road and origin considered at (0, 0). Z-coordinate of the model is considered as height of the road profile at required interval of road sections. The changes in height of progress that linked with productivity of the activities show the realisation of surface changes in a graphical image of the ground profiles of the road. The visualisation model has a capability to render the surface in both solid and mesh format. The model has developed assuming origin and side slopes constant according to geometrical design data of road.

2.4 Output

The output of this visualisation model will be a decision support tool that assists the project planners/managers to develop an efficient construction plan of earthwork activity in road construction and reduce the communication gap among project stakeholder by building consensus to enable construction managers to improve the productivity and reduce resources waste using the Innovative Visualisation Model.

3 CASE STUDY

A demonstration case study involving, a 1.5 km of road section of lot no. 3 road project in Portugal was selected for site data generation and to test the developed model in order to generate automatic graphical images of road profile for mass earthwork activity. For this purpose, actual road design parameters and geometric data of L - section and X-section is considered and sectional quantity of earthwork is calculated assuming the typical trapezoidal sections at 25 m interval along the selected length of road section. The max cut/fill section is identified where construction operations start first as per existing practice and the construction site knowledge. The height is calculated using the equation no 2.

In this case study, height is presented as Z- coordinate where as X direction is along the road and Y direction is cross section. The road surface is presented in terms of height in mesh form. Productivity of the selected activity is the key variable to identify the next surface/layer during the construction progress. In this case productivity rate is considered on weekly basis. The next surface/road profile was developed based on remaining sectional quantity after progress of earthwork equivalent to the weekly productivity. Similarly road profiles have been generated till the sectional quantity is achieved to the final design level on a weekly basis for selected road length. Similarly, operations are repeated for next economical stretch of length where the cutting and filling operation take places and profiles can be generated automatically as mentioned above for rest of the road length. The economical haulage distance is determined using DynaRoad software and integrated into the visualisation model to visualise the optimum haulage of mass earthwork along the road to reduce the wastage of resources and improve productivity.

In this case, only design data is validated and actual progress and profile is not included in this paper. The comparison of actual profiles with automatic generated profiles will be performed in later stage. The result of case study is presented in the graphical images as shown below. The graphical images generated of road profiles during construction operation on weekly basis are presented in figures 6, 7, 8 and 9.

Figure 6 shows the images of road profile generated at week 3 & 4 and location of transformation cutting and filling mass earthwork during construction operations at the end of week 4. Similarly, figure 7 shows a snap shot of the graphical image of the road profile that was generated by the model at the end of week 4.

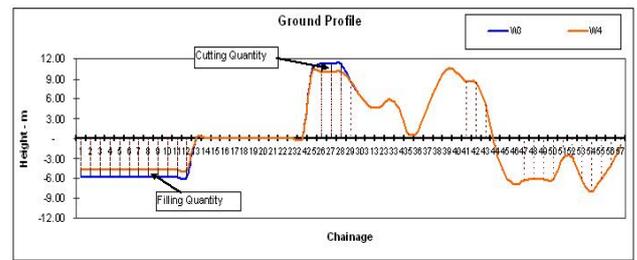


Figure 6. Graphical images of Road profile generated during construction operation at week 3 and week 4.

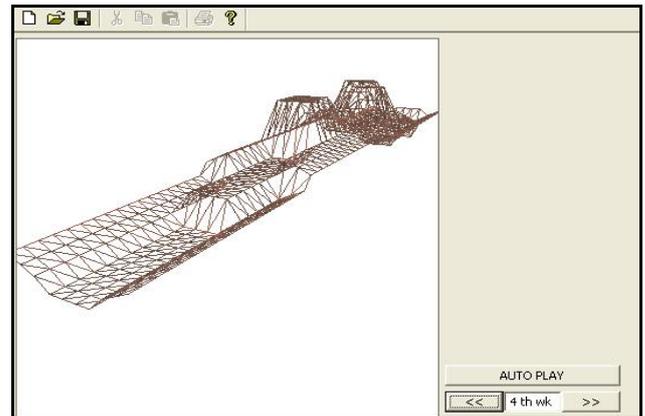


Figure 7. Snap shot of generated graphical image of road profile by IVM at week 4.

Figure 8 show the image of the road profile generated at week 9 & 10 and location of movement of cutting and filling mass earthwork during construction operations at the end of week 10. Figure 9 shows a snap shot of the graphical image of the road profile that was generated by the model at the end of week 10.

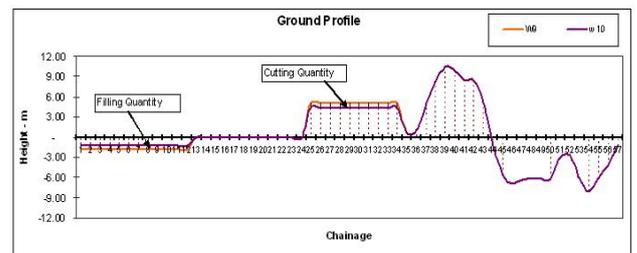


Figure 8. Graphical image of Road profile generated during construction operations at week 9 and week 10.

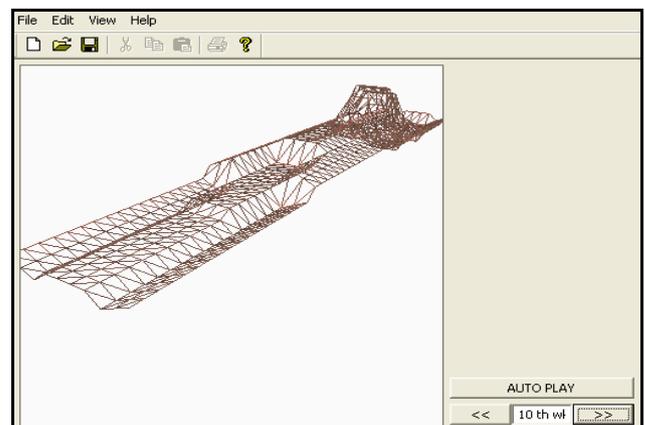


Figure 9. Snap shot of generated graphical image of road profile by IVM at week 10.

Similarly, the road profiles have been generated throughout the construction period. In this case study, the road profiles has been generated on a weekly basis throughout the construction period that has taken 22 weeks to complete the earthwork activity of the road project.

4 FURTHER STUDY

In this paper, earthwork activities of a road project have been considered for the development of an innovative visualisation model of ground profiles in a road project. In future, other activities involved in road projects will be included to develop the whole model of construction process.

Additionally, the innovative visualisation model for ground profiles of road project will be optimised for the key influencing factors such as access points using some search engines including genetic algorithms.

5 CONCLUSION

An innovative methodology has been formulated through the derivation of mathematical formula in order to determine the coordinate data for automatic generation of road profiles and a framework for a visualisation model of ground profiles has been developed using the road design data, productivity of activity generated by RoadSim simulator and construction site knowledge base.

It is concluded that the developed innovative visualisation model of ground profiles assists project managers/planners to communicate construction scheduling information through graphical simulation and visual evaluation of automatically generated road profiles that facilitates a logical decision-making process on construction scheduling and resources planning.

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