AN INNOVATIVE APPROACH FOR IMPROVEMENT OF COMMUNICATIONS THROUGH VISUAL SCHEDULE MODEL IN ROAD CONSTRUCTION

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ABSTRACT: *Innovative Visualisation Technologies applied to construction simulation and optimisation have the potential to improve communications and coordination amongst the construction team. In this context and in the drive for innovation in the construction management, a framework for automatic generation and visualisation of construction processes in road construction has been conceived, designed and developed. The framework is composed of road design data, quantities of cut and fill, productivity models, algorithms for modelling ground profiles and road profile visualiser. The paper details a Visual Schedule Model (VSM) that has been developed in the course of this research to realise the framework outlined above. The model is currently being evaluated using real life case study. Conclusions and future development have also been presented.*

KEYWORDS:
Innovative methodology, Visualisation model, 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 management. Current practices in the construction industry suggested that road construction projects often overrun in budget and time due to change order, geological and environmental factors, and potential conflicts with stakeholders, social activities and a large number of unpredictable factors. In addition, 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.

Development of construction scheduling is an important task of the project management process 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 suggested that a considerable amount of time in an 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 needs to develop a detailed schedule depending on the complexity of the project and the intended user of schedule. Personnel involved in the execution stage of work need a breakdown of master schedule into a detailed schedule. Such schedule includes detailed information of daily production rate and quantity to be performed and resources required. Thereby enables to plan more effectively and manage the day-to-day tasks effectively at construction site. Project planners will enable to develop construction schedule more effectively considering the non-productive time related to waiting in presence of a visualisation model.

The development of a visualisation model of road construction schedules is the second stage of "RoadSim" simulator. The RoadSim is a construction site knowledge-base driven construction simulation system to develop a master schedule of road construction project. The 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 productivity and unit cost of road activities (Castro and Dawood, 2005).

Various research studies have been conducted in building projects, in the area of construction scheduling and visualisation. Dawood and Mallasi (2006) formulated an innovative 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 workface using visualisation/simulation tools. Also, Mallasi and Dawood (2001) concluded that a congested workspace was a factor in decreasing the productivity of 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.

Visualisation models have been researched and utilized at the design stage but their use in construction planning and scheduling is still limited, especially in the 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. A few 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 produce an independent platform and deal with 3D visualisation in 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 earthwork movement activity for the realisation of intermediate stage in forms of graphical images during construction operations in civil engineering projects using morphing techniques. However, the authors did not address particularly in the ground profiles generation based on variable production rate throughout the construction operation.

In this paper, the research study focuses on innovative methodologies for visual automatic generation of ground profiles in order to analyse the visual impact in the construction schedule communication and resource planning. This includes resources utilisation, idling of equipment and manpower, and location of activities that are under execution and construction methods throughout the construction process. This will assist to improve the communication line of scheduling information amongst project team and support the decision-making process in the construction scheduling and resources planning processes. The following section details the component of the framework.

2. FRAMEWORK OF THE VISUAL SCHEDULE MODEL (VSM)

The general specification of the framework of the visual schedule model is outlined in Figure 1. The framework is composed of sectional cut/fill quantity, road design data, and productivity data produced by RoadSim and construction site knowledge base for automatic generation of road profiles throughout the construction operations. Key parts in the processing stage for development of the model are: development of detailed schedules, development of visualisation model. At a later stage of this research study, the framework will be optimised considering key factors such as access points or location of site offices using search algorithms such as genetic algorithms.

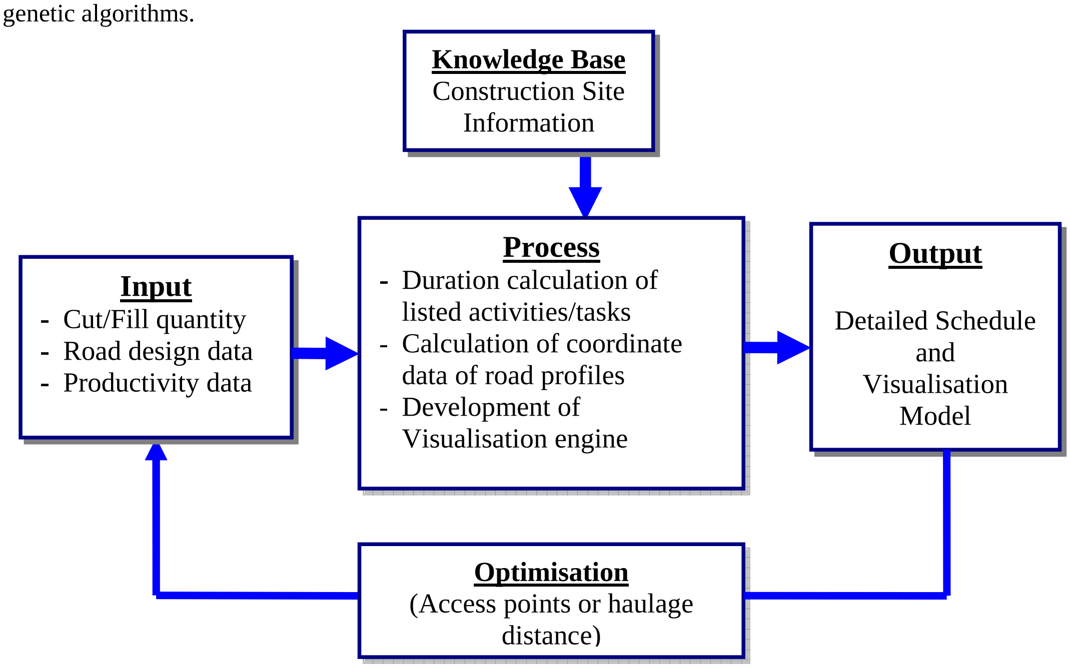


Figure 1: Framework specification of visual schedule Model.

2.1 INPUT

The sectional quantity of cut/fill along road section that is calculated using the road design data such as L-section and X-section at required intervals of chainage and productivity data are inputs of the visual schedule model. The productivity data, which is generated by RoadSim simulator based on available resources and known site constraints, has been incorporated with the model as a key input to determine the duration of the earthwork operations.

In addition, site survey information and construction knowledge base that assists to identify the possible site access points where the construction operation starts and a possible route for transporting materials have been integrated within the framework to develop the model. The soil characteristic of the road section, types of equipments, haulage distance, working conditions and all other factors that control the productivity were 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.

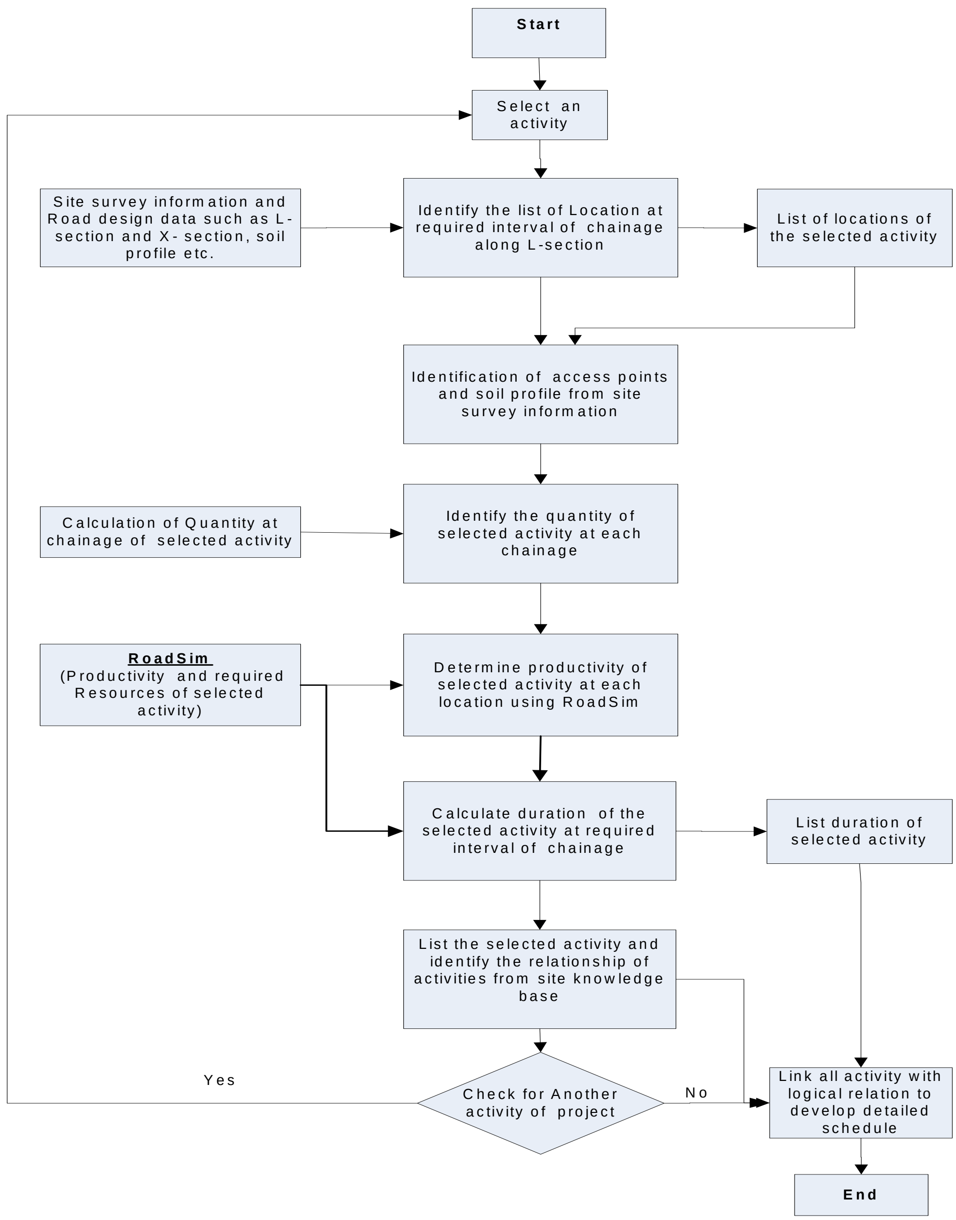


Figure 2: Information flow chart of detailed schedule development.

2.2 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:

2.2.1 SCHEDULE DEVELOPMENT

The lists of sections are defined at required intervals along the road using L-section profile for development of visualisation model. Site survey information and road design data such as L-section & X-section is used to identify a list of locations as per required interval and required accuracy. In addition, 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 at each and every location 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 selected activity. The process is repeated for other activities of road projects and the precedence relationship is established, based on the construction operation knowledge base.

2.2.2 COORDINATE DATA CALCULATION

A mathematical formula has been derived to determine progress of height for mass earthwork based on the 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 in slots 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 shape as shown in case (a) & (b). There are other typical sections that are rarely used and are not considered in this paper. The following section describes the development of the mathematical formula.

Case (a) Common typical road cross-section used in road projects presented here for mathematical model analysis:

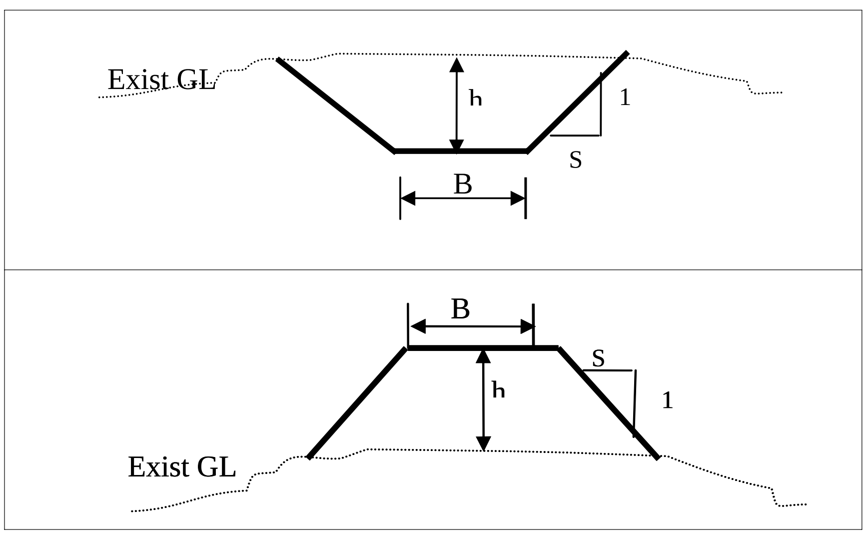


Figure 3: Typical cross-section for cutting and filling of road surfaces

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

- Road cross-section is considered as a trapezoidal shape having side slope S: 1.
- Ai = 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.

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

$$Sh_i^2 + Bh_i + (-\frac{Vi}{L}) = 0 \qquad \ldots (1)$$

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:

$$h_i = \frac{-B \pm \sqrt{B^2 + \frac{4SVi}{L}}}{2S} \qquad \ldots(2)$$

Case (b): Another type of typical road cross-section used for uneven terrain surface.

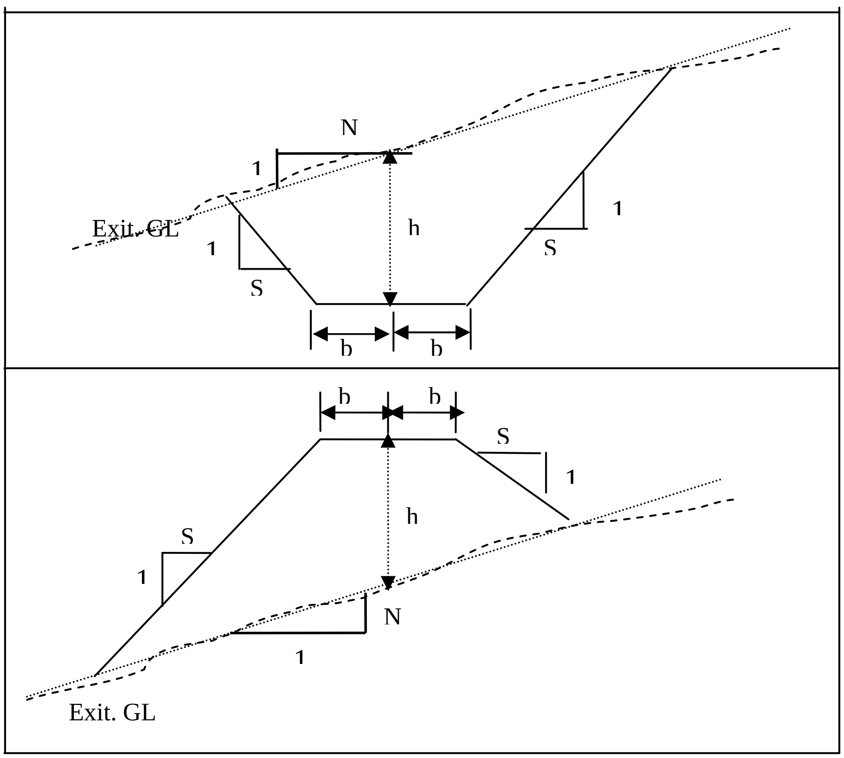


Figure 4: Typical section of road cross-section for irregular cutting terrain surface

After the derivation of the mathematical equation of area and volume for the section shown in Figure 4 and comparison with the quadratic equation, the height of cross-section (h) is determined using the Equation No. (3).

$$h_i = -b \pm \left[(\frac{1}{SN}) \sqrt{(\frac{V_i S}{L}) \times (1 - \frac{S^2}{N^2})} \right] \qquad \ldots(3)$$

Where:

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

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 ($\pm$ 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

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

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

$$h_i = \frac{-26.1 + \sqrt{(26.1)^2 + \frac{4 * 1.5 * 2834.70}{25}}}{2 * 1.5}$$

$$h_i = -8.39$$

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 visual schedule model.

2.2.3 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 is determined at every location of the required interval. The duration required to complete is calculated using the production rate provided by the RoadSim simulator under assigned set of equipment and characteristics of the soil. The visualisation model is based on 3D (2D plus height) of terrain surface in order to develop the rendered visualisation model.

The visualisation engine has been developed using the programming language; visual C^{++} and Direct X. The input of the visualisation engine is the coordinate data, which has been developed using innovative methodologies based on the mathematical model in Excel spreadsheet and saved as a text file. 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 the 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 the 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 the road.

2.3 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. This will reduce the communication gap among project stakeholders by building consensus to enable construction managers to improve the productivity and reduce the resource waste using the visual schedule model.

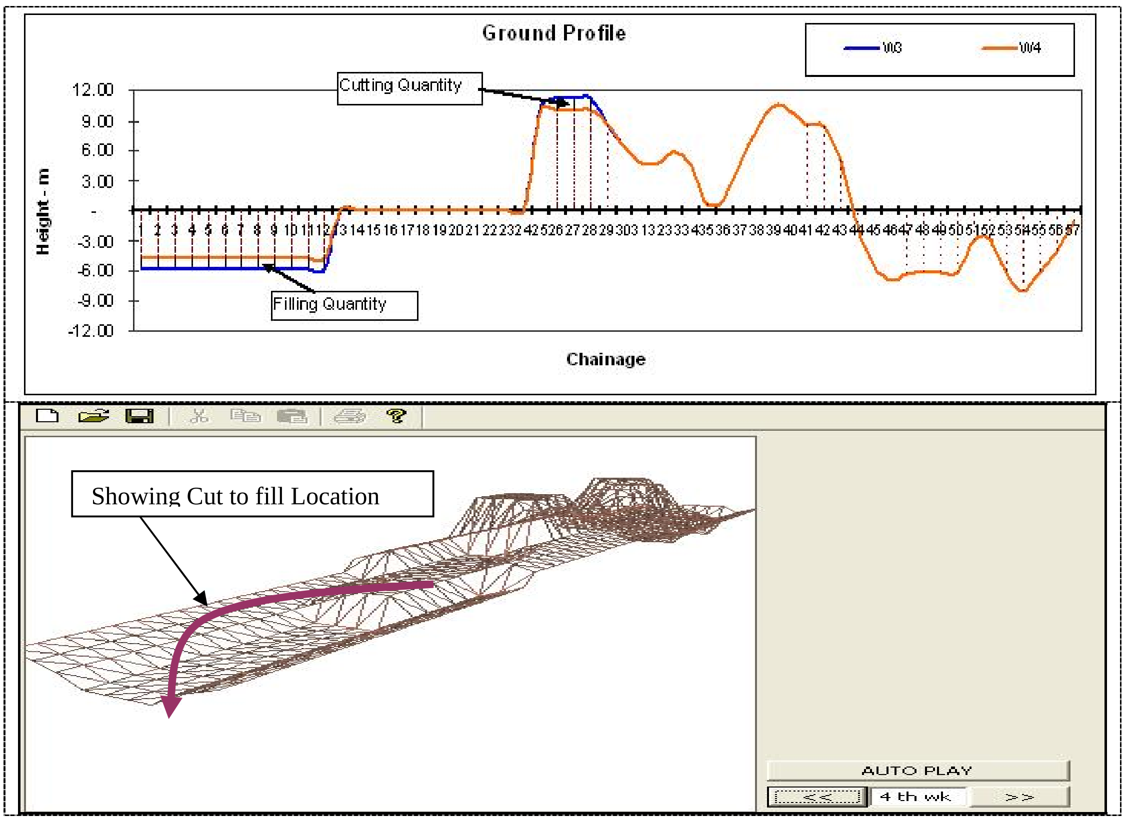
3. CASE STUDY

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 Eq. (2). The scale used to develop the visualisation model is different for x, y and z axis. For X axis, the length of load is presented in 1:25, Y axis in 1: 10 where width of road is presented and Z axis is presented as 1: 1 for altitude of the ground surface.

In this case study, height is presented as Z- coordinate where as X direction is along the road and Y direction is the 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 a weekly basis. The next surface/road profile will be developed based on remaining sectional quantity after progress of earthwork equivalent to the weekly production rate.
Similarly, operations will be repeated for the next economical stretch of length where the cutting and filling operation take places and profiles will be generated automatically for the rest of road length. The economical haulage distance is determined using DynaRoad software and integrated into the visualisation model to optimum the haulage distance of mass earthwork along the road to reduce the resource wastage and increase the 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 evaluated at a later stage. The result of the case study is presented in the graphical images as shown below. The graphical images generated of road profiles during construction operation on a weekly basis are presented in the Figures 5.

Figure 5 (a) shows the images of road profile generated at week 3 & 4 and the location of transformed cutting and filling mass earthwork during construction operations at the end of week 4. Figure 5 (b) shows a snap shot of the graphical image of the road profile that has generated by the VSM model at the end of week 4.



In this case, the road profiles that are generated on a weekly basis throughout the construction period need 22 weeks to complete the earthwork activity of the road project based on the productivity provided by RoadSim simulator.

4. FURTHER STUDY

In this paper, earthwork activities of a road project have been considered for the development of a visual schedule 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 visual schedule model of the road profiles will optimise the key critical factors such as access points or haulage distance using some search engines including genetic algorithms.

5. CONCLUSION

This study is concluded to adopt a prototype approach to design and develop a framework of interactive visual schedule model and validated through a real life case study to improve the communication gap amongst construction team through development of detailed visual scheduling and efficient resource planning. In this context, an innovative methodology has been formulated through the development of mathematical algorithms to determine the coordinate data for automatic generation of terrain profiles. The framework of visual schedule model has been developed by integrating the road design data, productivity produced by RoadSim simulator and construction site knowledge base.

The model is validated through the real life data of a road project recently completed in Portugal. The model is able to generate visual images of the movement of earthwork at a slot of time. This assists to analyse the required resources and available constraints to produce the effective construction plan and improve communication at site level. This is the main contribution of this research study. It concludes that the developed visual schedule model of terrain profiles of road assists project managers/planners to communicate scheduling information through graphical simulation. Thus facilitates a logical decision-making process on construction scheduling and resources planning.

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