International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

Analysis for Tunnel Construction Technology

Areeb Ahmad[1]
[1]PG Student, Construction Technology & Management,
Al-Falah School of Engineering & Technology,
Al-Falah University, Haryana, India,

Masoom Reza[2]
[2]Civil Engineering Department,
Al-Falah School of Engineering & Technology,
Al-Falah University, Haryana, India

***Abstract*:- Tunnel construction in infrastructure projects plays an important role for enhancing the transportation networks, especially in congested cities. Tunnel projects are classified by long durations, large cost projects, complexities, repetitive construction tasks, risks, and uncertainties. Many construction techniques have been developed in tunnel construction industry to improve the construction of tunnels and decrease its impact on ground movements and its surrounding structures. This paper presents a structure for planning tunnel construction using simulation technique. The tool aids contractors in estimating the required time and cost for tunnels construction. Many construction methods and techniques have been made into consideration for the development of this tool which can be used on ground with different techniques. The proposed structure consists of three modules: (a) simulation technique,(b) tunnel analyzer module, and (c) decision support technique. This structure can be utilized in selecting the best construction technique using fuzzy group decision-making method based on time, cost and other selection criteria that could be defined during the decision-making. This decision method is characterized using different supporting alternatives by a group of experts and a predefined set of criteria.**

Key Words: Planning, tunnel construction techniques, computer simulation, cost and scheduling, decision-making.

1. INTRODUCTION

In general, tunneling construction processes are quite complex. Many variables are involved which interact with each other and many resourced are used. Hence, it is quite difficult to explain the reasons for scheduled delay and cost over-runs in these processes. In order to understand and improve the tunneling construction processes, and consequently minimize the sources of delay and increasing costs, various types of methods and tools have been developed. In construction models are also used to solve problems like planning and control, project scheduling, cash flow management and resource management.

A sensitivity analysis has been carried out on number of the case studies, to analyze the most sensitive tunneling variables affecting productivity. Based on the sensitivity analysis, comparison between the productivity achieved on site and the calculated productivity (theoretical), the validity and effectiveness of the model was assessed. Subsequently, two simulation model were developed using EZstrobe simulation software and similar sensitivity analysis was carried out. It was determined that the simulation models produce logical results, then different resource combinations were examined to evaluate the impact on productivity and cost. Based on productivity and cost, also a comparison was made between the TBM (Tunnel Boring Machine) and D&B (Drill and Blast) excavation methods. This type of techniques can be used in real projects to make decisions as to what excavation method or resources to use in real projects by the project manager.

2. METHODOLOGY

2.1 Simulation Technique Used In Project

The purpose of this chapter is to realize understanding regarding the method of building simulation models. Also, a far better understanding of the utilization of simulation for various styles of analysis of tunnelling construction processes is pursued. Furthermore, critical tunnelling variables are identified from existing simulation models of tunnelling construction. These variables are utilized in the deterministic and simulation models and analyzed by means of sensitivity analysis. “The process of designing a model of a true system and conducting experiments with this model for the aim either of understanding the behavior of the system or of evaluating various strategies (within the bounds imposed by a criterion or set of criteria) for the operation of the system”

2.2 Building Simulation Models

“The process of determining whether a simulation model is an accurate representation of the system, for the objectives of the study”. Credibility is defined as “A simulation model and its results have credibility if the decision-maker and other key project personnel accept them as correct” (Law, 2006).

The seven steps approach developed by Law includes:

1. Problem formulation,
2. Collect information and construct an assumptions document,
3. Validation of the assumption document,
4. Program the model,
5. Is the programmed model valid,
6. Design, conduct, and analyze experiments,
7. Document and present the simulation results.

For a more in-depth explanation about this approach see Law (2006). A graphical representation of the seven-step approach is shown in figure 1.

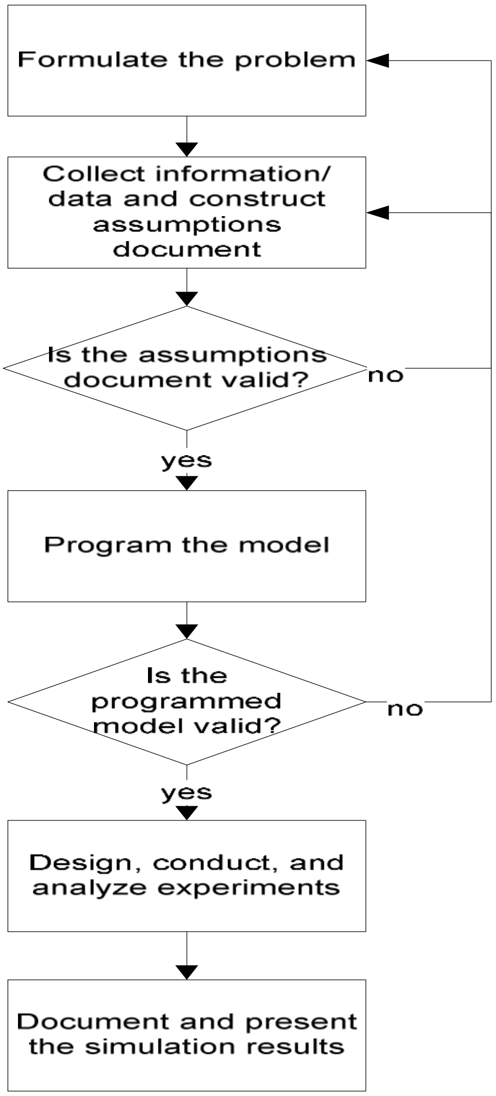

Fig 1: A graphical representation of the seven-step approach

2.3 SIMULATION SOFTWARE

Multiple simulation software is available for modelling construction processes. Simulation tools will be highlighted in this paragraph. Subsequently, the main target will be on the EZstrobe simulation software, because this simulation software will be used in this research. EZstrobe is used during this research as simulation tool mainly for two reasons. The software is easily available for academic purpose. Furthermore, it is an easy tool to learn system and ideal as a first simulation tool, capable of modelling complex problems with little effort.

2.4 EZStrobe

EZStrobe is a simulation system designed for modelling construction activities. EZstrobe is based on the principals of Activity Cycle Diagrams and uses the Three-PhaseActivity scanning paradigm. It is designed to satisfy the need for an easy to understand and capable of modelling complex problems with little effort.

The EZstrobe model shows the various activities that are used in construction operation, and the various resources utilized. Basically, the three main factors the model are: the activities, the condition under which the activities works, and the result of the activities when they end. The models are shown using activity cycle diagrams (ACD). ACD's are networks of circles and squares that identify the idle resources, activities and their precedence. Such as rectangles representing activities, circles representing idle recourses, and lines representing the flow of recourses. In EZstrobe models, all activity start-up conditions and results are in terms of resource amounts (Martinez, 2001).

3. USE OF SIMULATION IN TUNNELING CONSTRUCTION

Simulation in tunnelling construction has been used for various objectives and had multiple contributions.

Application of special purpose simulation modelling for tunnel construction; Ruwanpura et al. (2001), AbouRizk describe the design, developments and application of special purpose simulation tool for tunnel construction operations. Using the special purpose tunnel template developed with symphony, the model and analysis of the tunnelling process for boring machines is explained. The tunnel template is able to do the following:

Predicting the tunnel advance rate;

- Balancing the construction cycles at the tunnel face and the shaft, and optimize the use of TBM, crane and trains;
- Predicting of the productivity, cost, schedule, and resource utilization based on simulation analysis.

The tunnel template also has unique features that can be used to analyze the tunnelling construction process, these are:

- Cost planning engine
- Custom-built reports and statistics
- Simulation of hypothetical work conditions

The special purpose simulation model consists of various modelling elements. These elements are: main tunnel length, muck car, shaft- undercut, shaft-ground, undercut track, intersection, waiting track, breakout track, tunnel segment and TBM. These elements have different input parameters for simulation

In order to recognize the critical input parameters of the tunnel template, it has been tested using different data input. The subsequent parameters have been found to be critical:

Type of soil (and penetration rate of boring) Liner installation time

- Swell factor of soil
- The capacity and number of muck cars
- Train speed.

3.1 DETERMINISTIC MODELS

Deterministic models are mathematical models during which the outcomes are determined through known relationships among events, without random variation as compared with simulation models, use ranges of values for variables in form of probability distributions. During this research the deterministic model are developed to gain

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

better understanding of the tunnelling construction processes, and identifies the tunnelling construction variables that are import for the simulation study. Regression analysis will be applied to identify the relation between length of the tunnel and cycle time and advance rate of tunnel for the construction process. By comparing the results of the deterministic model with the results of the site case studies, and by performing a sensitivity analysis on the tunnelling effecting productivity, opinion can be drawn regarding the validity and reliability of the model.

In the calculation of the cycle time of the handling in tunnel construction projects, the excavation length can also be divided into small lengths when put next with the length of the tunnel (L) to ease the calculation of the cycle time and subsequently the productivity. However, unlike HDD technology, the cycle time of handling system used in the construction operation will change as excavation proceeds. The cycle time of the handling process increases, because the distance between the face and shaft of the tunnel increases as excavation proceeds. This guides to longer transfer times regarding the transportation of muck and material throughout the tunnel.

3.2 SIMULATION MODELLING

In the previous chapter a deterministic model was described and applied to the case study. Deterministic models are mathematical models in which outcomes are determined through known relationships among states and events. In actual site condition it means that only average time durations of activities, and average productivity of resources are considered. Also sensitivity analysis was performed on the model to incite the relationships between the variables i.e resources and the productivity of tunnelling.

Triangular distributions are applied in this simulation study to explain the time duration of activities. This sort of probability distribution is used in the simulation models because of the method of data collection. As to the value of the distributions, it is based on minimum, maximum and most probable knowledge of the interviewed construction managers of the field. If the most likely outcome is known, together with the smallest and largest value, a triangular distribution can be used to model the time duration of activities.It also displays the input parameters with its values and shows different kind of statistical data, such as utilization rate of queues (in %), time durations of activities and average durations, standard deviation, minimum and maximum values. However, the type of data that is of interest can be defined in detailed.

Applying the simulation model to the tunnel projects, the cycle time (in min) and productivity (in m/hr) are determined. A comparison is made between productivity observed on sites and productivity determined by simulation, to assess the validity of the simulation models. The tunnel projects were built using two different excavation methods- the drill and blast and the road header excavation methods was used for different sections of the tunnel project. The flowchart in fig 2 show the construction processes involved regarding the excavation method that was used.

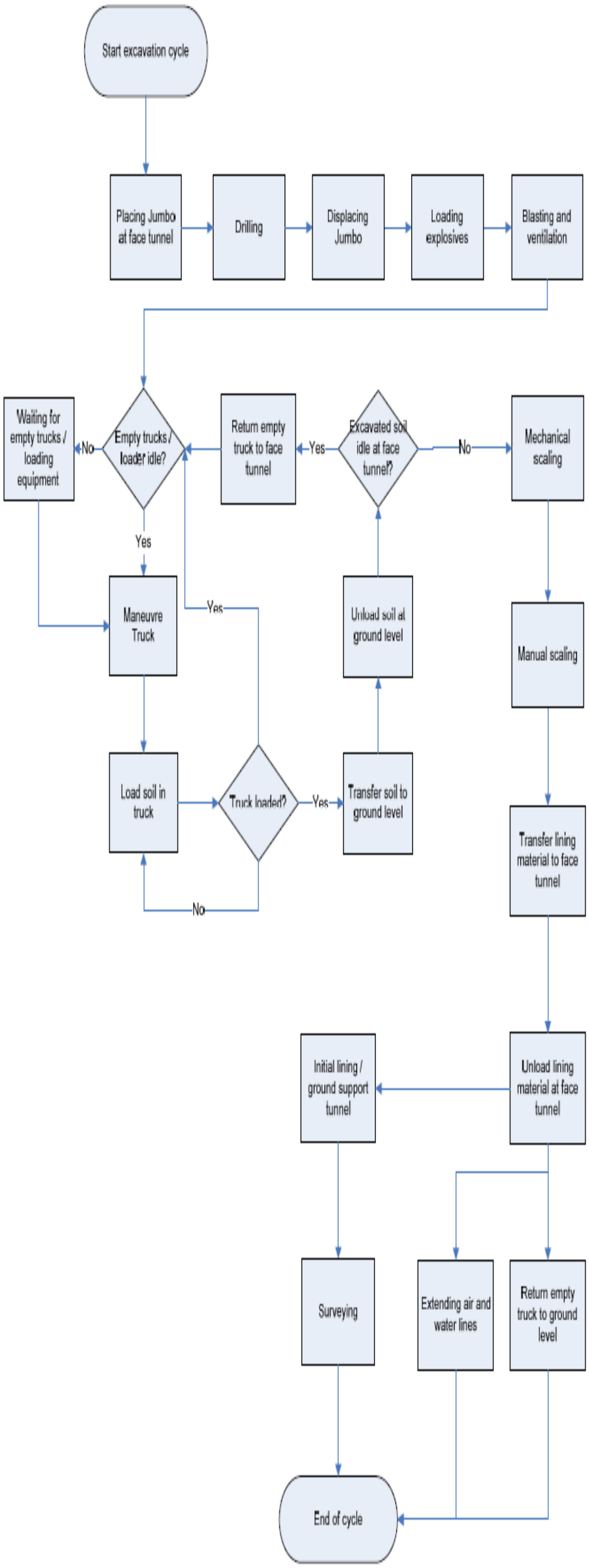

Fig 2: Show the construction processes involved regarding the excavation method

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

4. COMPARISON OF EXCAVATION METHODS

In table 1 for both excavation methods the tunnel advance rate and unit cost related to actual resource allocation, and tunnel advance rate and unit cost are calculated using various techniques and are represented related to best resource combination are described.

Table 1:Comparison of excavation methods

Excavation	Actual advance rate(m/hr)	Actual Unit cost($/m)	Advance rate(m/hr)	Unit cost($/m)
Drill and blast	0.271	5350.20	0.319	4580.73
Road header	0.312	4976.90	0.472	4261.92

5. VALIDATION OF SIMULATION MODELS

The validation of the simulation model is done by comparing the construction project site productivity (actual productivity) with the actual productivity of the project on the field. Besides the project site productivity, it is also compared with the calculated productivity of the deterministic model. The average tunnel advance rate of the tunnel project 1, excavated by drill and blast, calculated by the simulation model is 0.271 m/hr. The tunnel advance rate of the tunnel excavated by road header is on average 0.357 m/hr. While in actual, the average tunnel advance rate was 0.295 m/hr (drill and blast) and 0.306 m/hr (road header) respectively. Hence, the percentage of validity is 92% (drill and blast) and 86% (road header). Therefore, the designated simulation model is considered to be robust, and can be used to estimate the productivity of tunnelling construction projects of the same kind as the tunnel project. Table 2 describes the output of the deterministic and simulation models and their percentage of validity.

Table2: Deterministic and simulation models outputs

Excavation	Actual Adv. Rate (m/hr)	Deterministic Model (m/hr)	Simulation Model (m/hr)	Deterministic Validity (%)	Simulation Validity (%)
Drill and blast	0.295	0.269	0.271	91	92
Road header	0.306	0.384	0.357	80	86

It is showed that a best allocation of resources can be determined based on productivity (m/hr) and cost ($/m). Using the decision index method the most effective solution was determined, by optimizing both productivity and cost. Simulation method was also used to compare the road header and drill and blast excavation methods based on productivity and cost. It was determined that the road header excavation method achieves higher productivity (in m/hr) and a lower unit cost (in $/m) than the drill and blast excavation method. The comparison is made assuming a tunnel with similar tunnel dimensions (cross section area and tunnel length) and soil properties is excavated by both methods.

6. CONCLUSION

In this research, the behaviour of tunnelling construction using deterministic and probabilistic simulation models were described. Using the deterministic model, several sensitivity analysis studies were performed. The effect of the following variables on the tunnel advance rate was assessed: number, capacity and speed of trains and trucks, number of muck and material cars per train, penetration rate of TBM and road header, stroke length of TBM, number and capacity of loaders, number of road headers, number of cranes, and speed of crane system. Furthermore, the affect of the advance rate of primary support, swell factor of soil, cross sectional area of tunnel, length of excavation per cycle, height of vertical shaft, and efficiency factors, on the tunnel advance rate (m/hr) was investigated. All these variables have a significant impact on the productivity of tunnel construction.

By comparing the calculated productivity (in terms of advance rate) with the productivity of tunnel on site for each case study, it was determined that the productivity as per actual site for each case study was close to the productivity calculated by the deterministic model. The validity of the tunnel project is 80% (tunnel excavated by road header) and 91% (tunnel excavated by drill and blast).

By comparing the calculated productivity with the productivity of the ongoing tunnel project, the validity of the models was assessed. The percentage of validity of the tunnel simulation models is 86% for the tunnel excavated by road header, and 92% for the tunnel excavated by drill and blast respectively. Therefore, concluded that the developed simulation models are robust and can be used to determine the productivity of tunnelling construction projects of the same kind as the tunnel (drill and blast and road header excavation).

Using the deterministic and simulation models it is accessed and presented that the tunnel advance rate is a function of the complex interaction between the excavation (TBM or road header, drill and blast) handling, the primary support, ground conditions and tunnel dimensions processes.

7. REFERENCES

[1] Joint Code of Practice for Risk Management of Tunnel Works in the UK, British Tunneling Society / Association of British Insurers, London.

[2] Planning of tunneling projects using computer simulation and fuzzy decision making, Mohatassem Abdallah, Mohamed Marzouk, Journalof Civil Engineeringand Management ISSN 1392-3730 print/ISSN 1822-3605 online 2013 Volume 19(4): 591_607.

[3] Peurifoy, R.L., Construction Planning, Equipment and Methods, 2nd edition McGraw-Hill, New York, 1970.

[4] Ang, A.H.-S., Tang, W.H., 1984. Probability concepts in engineering planning and design. In: Decision, Risk and Reliability, vol. II. Wiley, New York.

[5] AbouRizk, S.M., Halpin, D.W., 1991. Probabilistic Simulation Studies for Repetitive Construction Processes. Journal of Construction Engineering and Management, ASCE, 116 (4). Pp 575-594.

[6] Ahuja, H.N., Nandakumar, V. 1985. Simulation model to forecast project completion time. Journal of Construction Engineering and Management, ASCE, 111 (4). Pp 325- 342.

[7] CHITKARA, K.K, 2004 “Construction Project Management”, Tata McGraw Hill, New Delhi, 2004.

[8] S.W. Nunnally, Construction Methods and Management,second edition, Prentice-Hall,1986

[9] ITA. 2004. Guidelines for tunneling risk management, (S. DegnEskesen et al.), Tunneling and Underground Space Technology 19, pp 217–237.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 10, October-2020

[10] Kopásek, J.: SW for simulation of functionality of road tunnel technology equipment, Eltodo EG. User Manual, pp. 68–73 (2013)
[11] TP98: Technological equipment of the road tunnels, Design document, pp.40—42, Eltodo EG (2013)
[12] Ni, D.: Lecture Notes in Traffic Flow Theory – A Unified Perspective, University of Massachusetts Amherst (1994)
[13] Wiedemann, J. and Potthoff, J., "The New 5-Belt Road Simulation System of the IVK Wind Tunnels - Design and First Results," SAE Technical Paper 2003-01-0429, 2003
[14] 3D CAD modeling and visualization of the tunnel construction process in a distributed simulation environment; Proceedings of the 2010 Winter Simulation Conference
[15] BIM and Advanced Computer-Based Tools for the Design and Construction of Underground Structures and Tunnels; By PanayotisKontothanasis, Vicky Krommyda and Nikolaos Roussos; Published: July 27th 2019
[16] Research on BIM-Based highway tunnel design, construction and maintenance management platform; Earth and Environmental Science 218 (2019) 012124.
[17] Design and construction of tunnels in zones subjected to high convergences; H. Bhavsar IL&FS Transportation Networks Limited, India. World Tunnel Congress 2014.
[18] Study of the stability of tunnel construction based on double-heading advance construction method; Zhanping Song, Guilin Shi; January 13, 2020.