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Construction Robots and Advanced Digital Technology Utilization to Improve the Productivity for Tunnel Boring in Infrastructure Projects

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Abstract: *Due to rapid growth in metro, rail, road, and hydropower projects, India will become the fastest-growing tunnel construction sector in the next five years. While tunnel construction began in India in the 19th century, little is known about the factors that influence tunnel efficiency and their effect on project completion. Time and cost overruns in large tunnelling schemes show this. The research looks at these aspects as well as the use of construction robotics and advanced digital technologies to improve TBM efficiency by designing and conducting a more effective tunnelling operation. The factors have been identified by extensive literature exploration in the current process, and a questionnaire will be sent to tunnelling experts to review the factors and their rated significance. The model will be tested using case studies of comparable type, and inference will be drawn. Contractors should predict the timeline and expense of tunnelling projects based on their productivity while bearing in mind the subjective impact of variables. Also, the factors that affect the use of construction robots and emerging technology to increase productivity.*

Keywords: Tunnelling, TBM, productivity, Construction Robots, Digital Technology, Innovative Technique, Innovation in Construction, Latest technology

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1. Introduction

Work on the site While construction is the largest and one of the most important industries in most developed countries around the world [1,] the use of robots and advanced digital technologies for better productivity on the job site is very limited. Tunnels are used all over the world to link towns, cut through mountains for road or rail tunnels, carry water in dams, and dive deep into mines. These tunnels play a vital role in everyday life, and their demand and use will increase in the coming years. However, tunnel construction costs a lot of money [2].

Tunnel boring was first performed about 150 years ago. Except for the 1.5 km Shakespeare tunnel in Dove [3], the lack of expertise in tunnel design contributed to shortcomings in the preliminary attempts over a century ago. Instead of digging and blasting, tunnel boring machine (TBM) excavation is a very easy way of excavating, lining, and supporting the tunnel [4]. TBM faces more time and cost delays in a tunnel than drill and blast in unfavourable environments such as mixed strata, broken soil, and fault zones [5]. The ability to forecast the right penetration rate estimate for a definitive project timeline is a crucial factor in the successful completion of tunnelling using TBM. With further technological advances in the 1960s and 1970s, the use of TBMs increased, allowing efficient tunnel boring in more reliable as well as less capable rocks at higher advance rates [7].

When it comes to tunnel construction, the biggest concern is not the troublesome sections, which account for just a limited percentage of the overall tunnel length, but these few per cent will greatly increase the construction time. Even though the tunnelling method has been used all over the world, the factors that influence the performance of the construction process are not well understood by industry stakeholders. Enhancing and modelling the efficiency of tunnelling projects would be simpler with a clearer understanding of the variables impacting the tunnelling design process [8]. In light of actual case studies and a quantitative approach, no such general considerations are mentioned.

2. Literature Review

Productivity in Construction

The ratio of the index of output to the related index of aggregate input is known as productivity. Although there is no specific description for efficiency, several words are used to describe it, including success factor, production rate, and output per man-day of work [9]. In terms of the physical method, productivity is known as the ratio of input/output, i.e., the ratio of an associated resource's input to actual output (in generating economic value) [10]. The definition of productivity differs and determining a common productivity metric is difficult because each organization has its non-standardized internal processes [11].

Job per hour is a basic definition of efficiency in the construction industry. It offers contractors a starting point for enhancing on-site work, and it helps them to bring the project back on track with careful preparation. Contractors may define positive and negative patterns, as well as causes for high and low productivity as production, by calculating productivity.

Factors affecting construction productivity in the tunnel

Each aspect may have a different effect on assumptions and estimation. Construction, efficiency, contractual, financial and fiscal, political and societal, and physical risk factors can all be categorized into separate risk categories [12] [13]. Cost and time overruns in tunnel construction projects are often caused by conditions that are not factored into the calculation [14] [15]. There has been a lot of work put into linking tunnel output to geological and system influences.

Classification of Factors

A total of 148 variables were identified after a detailed analysis of papers, magazines, periodicals, and books, as well as a pilot survey and on-site observation. All 148 variables were grouped into six categories as seen below, based on their characteristics and the primary recommendations of experts. The variables are then grouped and assigned to categories. This grouping aims to aggregate all variables into a single category so that they can be defined more easily. The five major factors classification is mentioned below.

Management conditions

All site operations must be coordinated by distributing proper personnel at the proper time, in the proper venue, and with proper efficiency for construction work to flow smoothly.

- In today's mining projects, on-time or early project execution is more critical than ever because time delays cost contractors more money by reducing profit margins.
- By using TBM, the builder can be able to reach a quicker average construction time. Since the time it takes to acquire a TBM can be as long as 12-14 months, causing delays at the start, it is better to pre-purchase TBMs for mining projects rather than waiting for the entire delivery duration of the contract [17].

Environmental Conditions

Due to heavily weathered conditions, areas where tunnelling is performed often poses special difficulties for preparing to forecast its actions [17]. Due to a lack of technology in the field of geotechnical imaging, “Geology” between tunnel portals is one of the most significant factors shaping tunnelling costs [18] [19].

Physical conditions

TBM range is determined by the scale of the construction site and its usability. To lift the TBM into and out of the launching and retrieval shafts, heavy cranes need extra space on site, which will directly illustrate the size of the individual TBM pieces that can be transported in [20] [17]. For crane and trailer transport, a low-gradient surface is preferred. The use of curved alignments is prohibited. A TBM with an 8-10 m shield body would weigh over 130 tons, rendering access to a site carrying such a heavy load difficult in hilly areas.

Breakdown

Delays can cause up to 73 per cent of the excavation week to be inefficient [20]. In more than half of the scenarios, TBM use is exacerbated by delays and maintenance [7].
TBM cutting tools are subjected to wear during mining. Mechanical and electrical devices overheat as a result of the harsh environmental conditions, resulting in risk exposure [21].

Delay

Delay times caused by breakdowns of time reserved for mining limit TBM improvement and productivity [20]. Construction delays are one of the most common issues that impact costs, timeliness, efficiency, and safety. Clients, customers, consultants, planners, operators, contractors, and suppliers will all create delays.[22]

TBM Parameters in tunnel construction

For each project, the scores of each category of TBM (EPB or SPB) in each of these categories, as well as others, must be considered.
Any of the most common places to think about are: -

- Overall site power requirements and required site and working area
- Use and availability of additives
- Capital cost of equipment
- Disposal of excavated material
- Speed of excavation
- Local experience

The availability of the additives in both quantity and price and the ability to be allowed to use the additives may restrict the type of machine selected.[23]

3. Research Methodology

The strategy adopted to gather practical information from the undertaking site was systemized input from the questionnaires. The questionnaire was dispersed to the construction infrastructure development experts in various regions of India. The survey study was organized to give subtleties on the individual demographics, factors causing delays, and suggestions for mitigating the delays by utilization construction robots and advanced digital technologies. In the survey's initial feature, respondents' fundamental subtleties were inquired. Interestingly, in the following part, delay factors were analyzed on literature review were approached to be evaluated; lastly, in the last part, member's recommendations concerning the utilization of robots and digital technologies in construction.

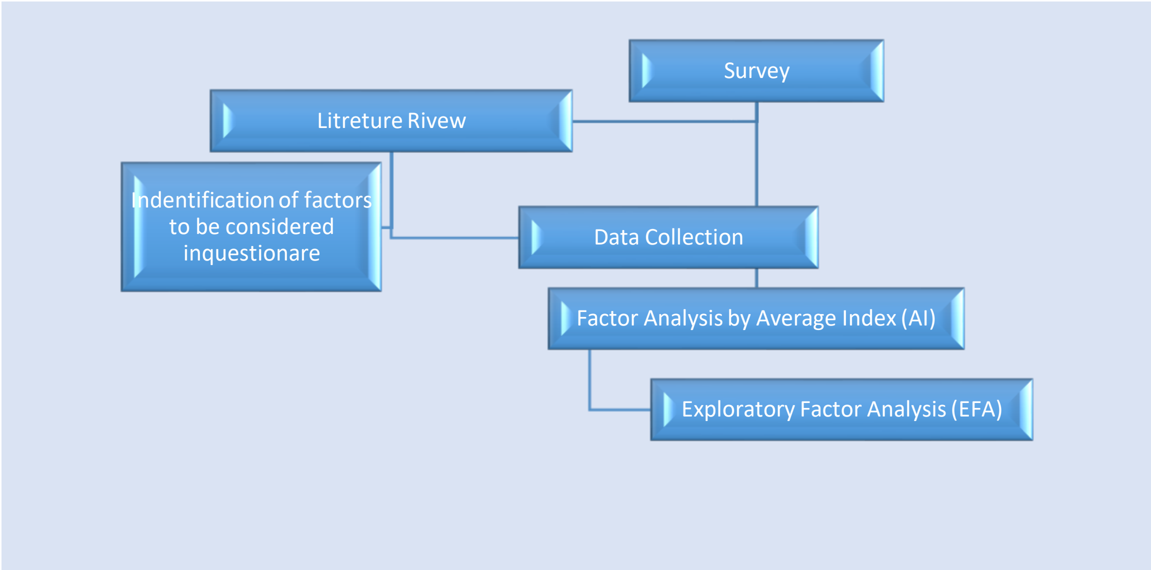

Diagram 1: Proposed framework of research methodology

Six main categories of delay factors were identified from 32 nos. of research articles, and seventy-eight factors causing construction delays. A total of 150 questionnaire survey forms were distributed to tunnel infrastructure professionals working on underground infrastructure projects, and only 120 nos of questionnaire forms were received from the respondent.

This study adopted a quantitative approach where the data was collected using a structured questionnaire survey. The questionnaire contained a list of delay factors together with 5 points Likert scale to capture the level of importance and its frequency of occurrence. For the level of importance, Likert scale 1 means very low and Likert 5 means very high while for the frequency, Likert scale 1 means never and Likert scale 5 means always. Regarding the sample size, this study used the following formula was used for the sample data collection:

Number of the sample, $n = \frac{N \times X}{(X+N-1)}$

Where N is the population size and $X = (Z_{\propto/2})^2 \times p \times \frac{(1-p)}{E^2}$

Zα/2 is the normal distribution with a confidence level of 95% and

E is the error margin and lastly, p is sample proportion.

Based on formula 1, the calculated sample size for this study is 120. Hence the study selected 120 respondents who are having more than five (5) years of experience working in railway/metro construction projects. These respondents are professionals working on major underground infrastructure projects. The respondents were clustered into the client, consultant or contractor across the project. However, only 120 of the respondents responded where the collected data later were compiled for analysis.

The collected data was evaluated through statistical techniques known as Relative Importance Index (RII) used to analyze the data to get the desired result. The formula was suggested by (Ferdin & Fassa, 2019):

Relative Importance Index, $RII\% = (\frac{\sum W}{A} \times N) \times 100$

Where W = weight given to each factor (importance/frequency) by the respondents (1-5),

A = the highest weight (in this case is 5),
N = total number of respondents.

Demographics of Study

The demographic questions inquire about the respondent's education level, work experience, and role in the organization. The findings suggest that most of the respondents work as consultants, which is about 42%, while 22% are customers, and the remaining 36% are said to be contractors. Fig. 1-3 specifies the respondent's history of work in the industry; the results suggest over ten years of experience consists 74 per cent of respondents; the respondents had 5-10 years of experience consists in survey results was 22 per cent, and only 4 per cent have less than five years of experience. The data received on the qualification of respondents indicate that 74% have obtained a bachelor's degree, while 18% have a master's degree and only 8% have Diploma certification.

Figure 1: Experience of Participants

Figure 2: Qualifications of the participants

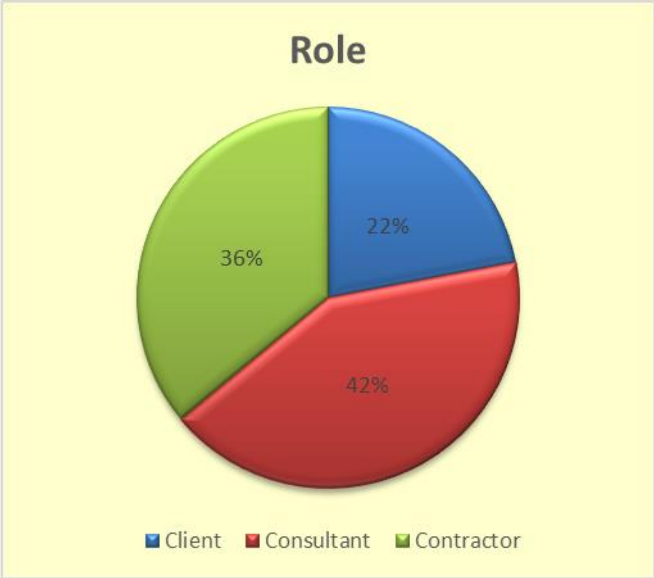

Figure 3: Role of the Participants

4. Ranking of Delay factors

Major identified delay factors are addressed in the survey and analyzed through the Relative importance Index (RII).

Delay Factors	Frequency of Cycle					Respondent	RII
	5	4	3	2	1	N	
Management Conditions	30	42	38	8	2	120	75%
Environmental Conditions	14	38	42	30	6	120	66%
Physical conditions	42	36	27	14	1	120	77%
Breakdown	12	40	47	18	3	120	67%
TBM Parameters in tunnel construction	18	22	66	10	4	120	67%

Table 1: Delay factors and their respective RII

Delay Factors	Frequency of Cycle					Respondent	RII
	5	4	3	2	1	N	
Construction Robots are future of infrastructure	55	43	12	10	0	120	84%
Digital Technology to improve efficiency	50	39	20	10	1	120	81%

Table 2: Benefits of Construction Robots & Digital Technology

5. Discussion and Conclusion

This study has discussed the significant factors responsible for causing delays in tunnel constructions in any infrastructure projects, major factors of delays are management decision and site condition followed by breakdown and tunnel parameters, and the construction robots and digital technology support are the future of infrastructure projects to increase efficiency and reduced cost.

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