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Development and Validation of a Delay Assessment Matrix for Road and Highway Projects

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Abstract – The study aims to gather information and assess the extent of delays and their impact on road and highway projects in India. The objective is to develop a delay assessment matrix for easy quantification of delay causing factors on project duration. A mixed method approach was used for data collection wherein information was gathered through literature review, questionnaire survey, interviews and responses under RTI act. The collected information was screened, verified and analyzed using statistical tools. Factor analysis was employed to arrive at a final list of 22 factors grouped in a 3x3 matrix having probability of occurrence vs. impact on project duration as the axes. The model was tested on a recently completed highway project using Monte Carlo simulation technique. The result of simulation was the increase in project schedule due to the occurrence of delays in the project in accordance with the specified probability and impact. The simulated duration of the project was in the range of 1095 days, 1229 days, and 1375 days for low, moderate and severe conditions respectively. The actual project duration was reported at 1116 days against contracted duration of 910 days. The simulated duration is found to be in close agreement with the actual duration of the project.

Keywords: Delay, Road and Highway Projects, Monte Carlo Simulation, Factor Analysis

1.0 Introduction

India is set to become the third-largest construction market by 2022 and is expected to invest nearly 50 trillion rupees for sustainable development[1]. The government has planned to allocate nearly 1,18,101 crores of rupees to the roads and highway sector. The construction rate in the highway sector has increased to an all-time high of 30km/day by end of September 2020 [2].

Flash report published by the Infrastructure and Project Monitoring Division [3] shows that a large number of central sector-sponsored infra projects will not be able to meet their deadlines. An analysis of 1737 central sector infra projects (costing Rs. 150cr and above) revealed that only 11 projects to be ahead of schedule and 213 projects reported to be on schedule. Nearly, 525 projects are delayed beyond their original schedules and nearly 90 have reported extended delays beyond their revised completion times. The anticipated cost overrun amounts to nearly 4,38,031.24 Cr which is nearly 19.61% of the anticipated cost of projects [3].

The objective of the present study will be to develop and validate a delay assessment matrix for easy identification and prediction of delay impacts on projects specific to the roads and highway sector.

2.0 Literature Review

Literature review was started by searching academic research databases such as ASCE, Springer, Science Direct, and Google scholar using “construction delay” as the title keyword and limiting searches to the civil engineering category and published within the years 2015-2020. The query yielded a total of 248 papers out of which 32 were shortlisted based on the abstract content and relevance to the study. The final 32 papers were thoroughly reviewed to gather more information related to delays.

It was found in the review that the delays are classified broadly into categories of 3 to 8 divisions. The basic classification involves dividing the delays based on the three stakeholders responsible for them viz., client, consultant, and contractor [4-7]. This classification has been further expanded by including accountability of more stakeholders i.e., designers, laborers, sub-contractors, financial agencies etc., [8-13]. Further, the delay categories can be based on the resources used such as delays due to materials, equipment or through functional areas such as contracts, procurement management, etc. [14-21].

The review showed 7 prominent factors reported by more than 50% of the authors. These include 1) Inexperienced personnel on-site, 2) Delay in site clearance, 3) Poor project planning and control, 4) Financial problems, 5) Payment delays, 6) Delay in approvals, and 7) Poor site management and supervision. The list of delays identified in the review are also in agreement with the report published by the Infrastructure and project monitoring division which includes delays such as land acquisition, approvals from forest departments, lack of infra support and linkages, delay in a tie-up of project finances, delays in scope finalization, and detailed engineering among others [3]. In similar standings, the taskforce report on project and program management lists delays such as uncertainty in land acquisition, delay in regulatory approvals, lack of comprehensive upfront planning and risk management, low maturity of project management processes among others [22].

3.0 Methodology

The methodology for the study was divided into three steps namely 1) Data collection, 2) Data analysis and 3) Matrix Validation – Monte Carlo Simulation.

3.1 Data Collection

A mixed-method research was used to combine the quantitative and qualitative research approaches [23]. The mixed-method approach allows for 'triangulation which will enrich and confirm the data collected for the study. It also provides a check on findings from one method with another [24]. A total of 32 detailed literature reviews, 100 questionnaire responses, and 25 RTI responses were collected for the study. Frequency analysis as mentioned in Equation (1) was used to rank the factors and methods based on their frequency of occurrence. Delay information from a total of 25 projects was listed through RTI responses from RTI responses.

$$Frequency\ (\%) = \frac{number\ of\ times\ factor\ or\ method\ is\ reported}{the\ total\ number\ of\ sample\ literature} * 100\% \quad \text{......... (1)}$$

A questionnaire was prepared and then sent to professionals engaged in the roads and highway sector. The digital form of the questionnaire was used and communicated via emails and social media. The questionnaire gathered information on the probability of occurrence of factors in projects (0% - 100%) and impact on the overall project duration (0% - 100%). The responses were checked for completeness and screened. A total of 100 responses were shortlisted for the study. The factors thus obtained were then grouped into a 3x3 matrix format as shown in Table 1. The probability was divided into three categories of low (<30%), medium (upto 60%), and high (>60%) whereas the impact was divided to low (<30%), moderate (upto 60%), and severe (>60%). The range of each category was decided based on the information revealed in questionnaire responses.

Table 1Delay Assessment Matrix

	Low Probability (<30%)	Medium Probability (Upto 60%)	High Probability (> 60%)
Low Impact (< 30%)	Low	Low	Moderate
Moderate Impact (upto 60%)	Low	Moderate	High
High Impact (>60%)	Moderate	High	High

For model validation, a recently completed highway project was taken up as a case study. The project was *"Four laning of Bhavnagar to Talaja section (Package-1) of NH-8E from 7.1 km to 53.6 km under NHDP-IV in Bhavnagar district on Hybrid Annuity Mode (HAM) [Package- I] in the state of Gujarat on Hybrid Annuity Mode under NHDP Phase- IV"*. The project details and project schedule are shown in Table 2 and Table 3 respectively. The key factors responsible for project delay are listed in Table 4 below.

Table 2Key Project Details [Source: 39]

Project Detail	Description
Name of Client	National Highway Authority of India
Name of Concessionaire	Sadbhav Bhavnagar Highway Private Limited
Name of Independent Consultant	Intercontinental Consultants and Technocrats Pvt. Ltd
Project Capacity	48.04 Kilometre
Project Cost as per Concession Agreement	998.18 Crores
Date of Signing of Concession Agreement	19.07.2016
Appointed Date	07.02.2017
Date of Completion	08.08.2019
Project Duration	910 Days
Construction Period	30 Months

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Project Detail	Description
Provisional Completion Certificate Issued on	With effect from 28.02.2020

Table 3Project Schedule

No.	Task Name	Duration	Start	Finish
1	Clearing and grubbing for road land, embankment slope, drain, etc.,	415 days	01-02-17	31-08-18
2	Dismantling of temporary structures	174 days	01-02-17	29-09-17
3	Providing and construction of embankment with approved materials	382 days	20-03-17	31-08-18
4	Providing and construction of subgrade/shoulder with approved materials	413 days	05-06-17	30-12-18
5	Earthwork in the filling of median/island area with selected earth	134 days	01-08-18	31-01-19
6	Providing and constructions of granular sub base	460 days	03-05-17	31-01-19
7	Providing and construction of dry lean concrete base	350 days	01-11-17	28-02-19
8	Providing and Construction of wet mix Macadam	197 days	02-07-18	29-03-19
9	Flexible Pavement Works	219 days	01-06-18	29-03-19
10	Concrete Pavement Works	394 days	01-12-17	31-05-19
11	Construction of CD works	370 days	01-02-17	30-06-18
12	Construction of New Bridges/ Underpasses/ Grade Separators/ ROBs	503 days	01-02-17	31-12-18
13	Drainage and Protective works	393 days	01-01-18	28-06-19
14	Toll Plaza Works	196 days	01-10-18	28-06-19
15	Miscellaneous Work	131 days	01-03-19	30-08-19
16	Temporary Safety During Construction	655 days	01-02-17	31-07-19

Table 4Factors Responsible For Delay in the Project

Factor	Impacted Activities (No. mentioned refer to Table 5)	Actual Delay of Project
Influence of other bodies	1, 3, 4 14	Provisional completion certificate issued with effect from 28 Feb 2020 against completion date of 08 Aug 2019. Total delay = 204 days Actual project duration = 1116 days
Problems at construction site	2,4	
Land acquisition	1,2,3,4	
Delay in design approvals	2,4	
Delay in approvals	2	
Tree cutting	14	

3.2 Data Analysis

The factors under each category group were subjected to factor analysis to bring about data reduction and selection of key factors responsible for the project's delay. Statistical package for social sciences (SPSS) software was used for the analysis. The factors were reduced using the principal axis extraction model. The number of factors to be retained were chosen using a combined technique based on Eigen score (>1.0); Scree plot test; and subject to each factor containing at least three measured variables. The oblique method of rotation was adopted as it provides a subset of variables with high loadings and rest with low loadings and thereby provides an interpretable solution. Pattern coefficient matrix was used for factor loadings. Bartlett's test for sphericity and KMO test (target value >0.70) were administered for testing sampling adequacy and measure of the appropriateness of data [40-43]. Internal consistency of each factor was assessed using Cronbach's alpha value (target >0.70) shown in Equation 2. The analysis resulted in a final matrix consisting of 22 delay factors grouped in a 3x3 matrix. This matrix should be used as a guiding tool for assessing delays on future projects.

$$\boldsymbol{Cronbach's\ alpha} = \frac{\boldsymbol{N * c}}{\boldsymbol{v + (N-1) * c}} \quad \ldots\ldots\ldots\ldots..(2)$$

Where, N = the number of items.
c = average covariance between item pairs.
v = average variance.

3.3 Matrix Validation – Monte Carlo Simulation

To validate the matrix, a Monte Carlo simulation was administered on project case data using @Risk Project Software. The project data and delay information were linked to one another and simulations were run in the software. For each iteration, the software plugs random task duration on linked activities according to the defined distribution and impact assigned. It then estimates new task duration and calculates a critical path to determine overall project duration [44]. The results of simulation i.e., total simulated delay of the project was compared with actual delay of a completed project to determine the model effectiveness as well as the relevance of the matrix for project applications.

4.0 Findings and Discussion on Results

4.1 Factors causing delay

The list of top ten delay causing factors reported through literature review, questionnaire survey, and RTI responses is shown in Table 5. Risk value is calculated using Equation (3) The main delay causing factors found from the literature review include delays due to site clearance problems, financial problems, procurement challenges, scope changes, approval problems, and poor project management practices. The main delay causing factors found through the questionnaire survey include site clearance, approval problems, scope changes, resource/vendor-related problems, coordination and communication problems, and variations w.r.t contractual agreements. The main delay causing factors include site clearance, financial problems, scope changes, and delays due to external factors such as weather. It is found that site clearance problems (including but not limited to site obstructions, site inaccessibility, encumbrances, local protests, lack of workspace, land acquisition problems etc.) and scope changes (including but not limited to scope creep, design and drawing changes, variations in work order items etc.,) are common across all types of projects and different stakeholders are in agreement.

Risk Value = Probability of Occurrence x Impact ………..(3)

Table 5Comparative List of Factors Causing Delay in Projects

No.	Literature review		Questionnaire Survey		RTI responses	
	Factors	**Freq.**	**Factors**	**Risk Value**	**Factors**	**Freq.**
1	Inexperienced personnel	18	Site accessibility problems	0.16	Land acquisition related problems	19
2	Delay in site clearance	14	Changes in prices	0.16	Changes in scope of work	12
3	Poor project planning and control	12	Lack of coordination	0.16	Weather related delays	10
4	Financial problems	11	Delay in Approvals	0.12	Delay in utility shifting	10
5	Slow payments	10	Poor quality documentation/ records	0.12	Tree cutting	8
6	Delay in approvals	8	Communication problems	0.12	Delay in electrical clearance	7
7	Poor site management and supervision	7	Shortage of resources	0.12	Public resistance to the project	6
8	Delay in procurement	7	Sub-contractor related problems	0.12	Financial problems	6
9	Change orders	7	Design errors	0.12	Encroachments/ site obstructions	6
10	Loss in productivity	6	Changes in scope of work	0.12	Forest clearance problems	6

4.2 Delay assessment matrix

The finalized delay assessment matrix is shown in Table 6. The matrix lists 22 delay factors grouped in a 3x3 matrix. The initial matrix was emailed to five experts to gather feedback on the feasibility of the matrix and recommended changes are incorporated into the matrix shown in Table 6.

4.3 Monte Carlo simulation

The risks assigned to the project schedule (Table 4)along with their assigned probabilities of occurrence and impacts on the schedule are shown in Table 7. The result of the project simulation is shown in Table 8. The simulation presents three scenarios of low, moderate, and high impact of the combined effect of delays on the project schedule. These are 1095 days, 1229 days, and 1375 days respectively. The actual project duration as determined from site records and news paper articles is reported at 1116 days from the start date to the receipt of the provisional completion certificate [45]. The actual project duration falls within the range of simulated project duration.

5.0 Conclusions

The present study aimed to develop and validate a delay assessment matrix for use in road and highway construction projects. The developed matrix resulted in a total of 19 delay factors grouped in a 3x3 matrix. The validation was carried out using data from a highway project and the schedule delays were simulated using the Monte Carlo simulation technique. The delays for the project were identified from the site while their characteristics (probability of occurrence and impact) were taken according to the matrix. The results from the simulation are in close agreement with the actual delays experienced on site. There could be an argument on other delays such as reworks, disputes, etc., The authors would like to clarify that the minor delays might overlap and occur within the ambit of major delays. When the schedule delays overlap, the impact of major delays has to be accounted for in the calculations. The delay assessment matrix should be used as a guideline for assessing delay impacts. The probability of occurrence and impacts of these delays might need minor adjustments based on project-specific conditions. In addition, site-specific factors or local factors have to be accounted for in addition to the delays mentioned in the delay assessment matrix.

Table 6 Delay Assessment Matrix

	Low Probability (<30%)	**Medium Probability (Up to 60%)**	**High Probability (> 60%)**
High Impact (>60%)	Contract termination (Black listing, financial closure problems)	Financial Problems (lending agencies, payment delays, shortage of funds, interest rate changes, etc.,)	Poor project management practices Poor planning and control Scope changes
Moderate Impact (up to 60%)	Delay from design/ project management consultants	Influence of external agencies/ stakeholders (railway, forest, electricity, water supply, local municipal authority, courts, etc.,) Poor documentation / records related problems Delay in Approvals (Land acquisition, Re-design, fresh drawings, Trees cutting, Utilities shifting, etc.,)	Obstructions to construction operations (protests, encroachments, new regulations, litigations, political motivation, etc.,) Issues in compliance to work/quality/standard/agreement requirements External factors (rise in fuel prices, taxation, dry/wet/cold weather-related problems)
Low Impact (< 30%)	Site/work-related disputes	Errors and reworks due to poor quality Engagement of inexperienced personnel (from any stakeholder team) Changes in working conditions/requirements not specified in the agreement Owner dominated contract Bureaucratic System	Site accessibility problems Poor site supervision and site management Communication and Coordination problems on site Procurement/resource-related challenges

Table 7 Risks Assigned to Project Schedule for Simulation

Factor	**Impacted Activities (Refer to Table 3)**	**Probability of Occurrence (Refer Table 6)**	**Impact on Schedule (Refer Table 6)**
Influence of other bodies	1, 3, 4 14	30-60%	30-60%
Problems at construction site	2,4	30-60%	>60%
Land acquisition	1,2,3,4	30-60%	30-60%
Delay in design approvals	2,4	30-60%	30-60%
Delay in approvals	2	30-60%	30-60%
Tree cutting	14	30-60%	30-60%

Table 8 Results of Project Simulation

Planned duration	912 Days	Three most critical delay causing factors: Land acquisition, Problems at construction site, Influence of other bodies
Actual duration	1116 Days	
Simulated duration (no delay impact)	912 Days	
Simulated duration (with delay impact)		
Low impact	1095 Days	
Moderate impact	1229 Days	
High impact	1375 Days	

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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