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Schedule Performance Analysis of Infrastructure Reconstruction Projects Due to Extreme Events

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Abstract

Timely post-disaster reconstruction of transportation infrastructures is vital, as it affects the pace of the overall physical and economic recovery of the disaster-ravaged area. To ensure the completion of the project within the optimum amount of time, it is important to know what factors affect the duration of the project, but it is difficult to find a comprehensive list of those factors in the current literature. This study aims to fill that knowledge gap by identifying the factors that affect the timely reconstruction of transportation infrastructures (PRTs) following a natural disaster. A survey was developed and distributed to collect data for this study, and the responses were analyzed statistically. It was found that the possibility of schedule overruns increases with the levels of complexity and damage. Hurricanes in particular cause sudden shortages of resources (experts, suppliers, laborers, materials, and equipment) that reduce the productivity and increase the duration of reconstruction projects. The results of this study will help practitioners and engineers take steps to complete reconstruction projects within the estimated schedule.

Keywords: identification of factors, post-disaster reconstruction, reconstruction time, transportation infrastructure

1. Introduction

Transportation systems are key to public mobility, access, economy, safety, and the environment [1, 2] therefore, it is essential that they be returned to a safe and operational state within the shortest possible time and within a reasonable budget after a natural disaster [3, 4]. For instance, critical highways were disrupted at four locations in the northwestern Los Angeles metropolitan area by the 1991 Northridge disaster [5], leading to substantial disruptions in the movement of people, and the closure of parts of Interstate 10 (Santa Monica Freeway) led to economic losses that were estimated at $1 million per day [6]. After the disaster in Aceh and Nias [7], the damages to the transportation systems were responsible for 19.7% of the total estimated damages caused by the disaster. Similarly, in 2004, in Sri Lanka, losses and damages to roads and other parts of the transportation sector accounted for 22% of the total damages. These are only a few examples of the socioeconomic disruptions that communities experience until the transportation systems are restored to their pre-event condition.

Natural disasters, especially hurricanes, create shortages of resources such as laborers, equipment, and materials that make it difficult for reconstruction to be completed within the estimated time [8, 9, 10, 11] and the public reacts by exerting additional pressure on the local governments when the contractors are not able to deliver their services on time [12, 13, 14]. In addition, the complicated, hectic, and dynamic nature of transportation reconstruction exacerbates other problems and increases the likelihood of schedule overruns and reworks [15, 16]. The dearth of research that addresses the issue of schedule overruns makes it difficult for practitioners to complete their projects on time [17].

Therefore, this study aims to identify the factors that affect post-disaster reconstruction time of transportation infrastructures (PRTs) to fill the abovementioned gap of knowledge in the literature. Several objectives were formulated to fulfill the goals of this study: i) identify the potential critical PRTs that affect the post-disaster reconstruction duration of transportation infrastructures, ii) categorize the identified PRTs, and iii) identify the most significant PRTs. The result of this study will help practitioners and engineers take the proper steps to complete their reconstruction projects within the initially estimated schedule.

2. Literature review

Hurricanes cause serious losses and damages that result in serious disruptions in the U.S. [18, 19]. Hurricane Katrina and Hurricane Rita led to tremendous socioeconomic damages. The accumulated direct and indirect economic losses and damages after Hurricane Katrina amounted to roughly $1845 billion, while the primary estimation was $160 billion [20]. The destruction caused physical and psychological distress to the victims, adversely impacted the environment, and rendered many of the critical infrastructures inoperable. Transportation systems are one of the infrastructures most severely affected by disasters [21, 22, 23]. The storm surges that accompany a hurricane affect the coastal areas, damaging many of the roads and depositing large amounts of debris, which can increase the cost and delay recovery activities for a prolonged period [24]. Following Hurricane Katrina, for example, economic loss for debris removal was approximately $200 million [25]. Damaged transportation systems cause disruptions in traffic flows and slow the pace of overall recovery, resulting in more indirect than direct losses [26]. Thus, the reconstruction of transportation infrastructures is critical to the recovery of affected areas after any disaster [27].

In 1987 [28], Pinto and Slevin espoused that a project can be considered successful if it is completed on time, on budget, meets all its objectives, and satisfies the client. Various studies have been conducted on successful construction projects, using their definition [29, 30, 31, 32, 33, 34, 35]. Almost all researchers believe that staying within the budget, adhering to the schedule, and achieving a quality project performance, referred to as “the iron triangle” by Atkinson [36] is necessary for the success of a construction project [37, 38, 39, 40]. Transportation agencies are experiencing unprecedented pressure to deliver projects on time and on budget, with an adequate level of quality [41, 42, 43], and an obvious response to this pressure is to improve the project delivery process by adopting effective project management strategies [44, 45, 46, 47].

Every reconstruction project is unique in nature; hence it is difficult to determine the factors that will determine the success or failure of a project [48]. Similarly, it is difficult to determine the exact causes of schedule overruns in post-disaster reconstruction projects. Table 1 depicts the a few of the challenges that researchers have determined affect the success of post-disaster reconstruction projects by causing schedule overruns.

As shown in the table, Ika et al. [49] believed that ineffective designs are one of the main reasons for failing to complete a project within the estimated schedule. Delays in decision making during different stages of projects have also been attributed to delays that ultimately affect their success. The pace of recovery and the return of society to its norm is highly determined by the fastest possible recovery of the transportation infrastructures [50]. Hence, it is imperative that the reconstruction is completed with least possible schedule overruns [51]. Understanding and identifying the factors that will eliminate schedule overruns is absolutely necessary for this purpose [52], and this study aims to identify such factors.

Table 1. Challenges affecting success and schedule of post-disaster reconstruction projects

Challenge	Previous Study
Delays in delivering resources	[53, 54]
Inappropriate assessment	[55]
Ineffective design	[49]
Temporary paths	[56]
Difficulties in damage evaluation	[57]
Low pace of decision-making	[58]
Number and quality of inspections	[59]
Inability to relocate functions	[60]
Permitting and consenting	[61]

3. Research methodology

3.1. Framework

The four-step methodology shown in Figure 1 was followed in this study. In the first step, a comprehensive literature review was performed. After rigorously screening the articles, 89 were shortlisted for thorough study, and a list of potential PRTs was developed. In the second step, a survey was developed, pilot tested, and distributed. In the following step, the survey responses were statistically tested to identify the significant PRTs, and the results were interpreted, employing the expertise of the authors.

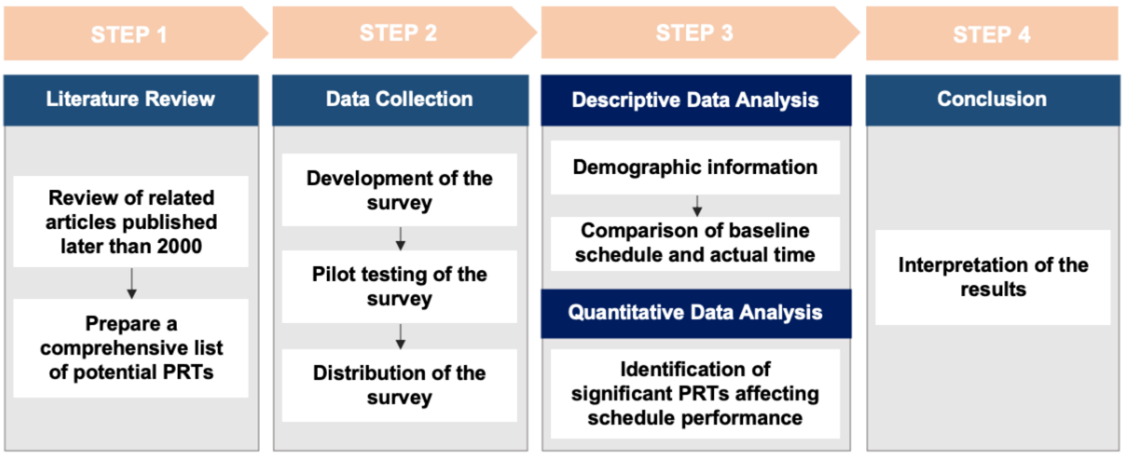

Fig. 1. Research methodology

3.2. Statistical tests

Three of the most popular and effective types of statistical tests were used for this study. The two-sample t-test was used for the continuous data that follows normal distribution, the Kruskal-Wallis was used for the seven-point Likert scale data that does not necessarily follow a normal distribution, and the Chi-squared test was used for the binary data of the survey questions that were answered by “yes” or “no.”

4. Data collection

4.1. List of potential PRTs

More than 200 relevant peer-reviewed journal articles, conference papers, dissertations, and research reports published on post-disaster reconstruction of transportation systems were collected for this study. Of those, over three-quarters of the articles were from journals because of the rigorousness of their review process. The research team established the following criteria for the articles that would be used: they must have been published in English after year 2000, they must be relevant to the post-disaster reconstruction of transportation systems, and they must be associated with engineering areas. After screening the articles, 89 of them were short-listed for thorough study. Short-listed articles were reviewed in depth to investigate the PRTs that significantly affect the cost and schedule performances, as well as the cost of reworks of post-hurricane reconstruction of transportation infrastructures.

Two main steps were taken to identify the potentially significant PRTs: i) identify the potential PRTs that affect the schedule performance post-hurricane reconstruction of transportation infrastructures; and ii) determine which of the potential PRTs were cited the most often, retain them, and exclude the rest.

A list of 30 PRTs was developed of substantial factors for successful post-disaster reconstruction. They were classified into eight categories: general information, physical characteristics of the project, damage level, resources, environment and safety, project management, local, and legal.

Table 2. List of potential PRTs

Category	List of PRTs	Category	List of PRTs
Physical Characteristics	1. Number of main/truck lines	Quality	16. Quality issues of materials
	2. Total length		17. Quality issues of equipment
	3. Level of complexity	Project Management	18. Frequency level of logistics/management issues
	4. Distance from highly populated area		19. Quality of on-site inspections
Damaging Level	5. Level of damage		20. Frequency of on-site inspections
	6. Level of traffic disturbance		21. Information management
Resource	7. Shortage of experts		22. Pace of decision-making process
	8. Shortage of field laborers		23. Implementation level of risk management
	9. Productivity level of contractors		24. Coordination
	10. Shortage of materials		25. Pace of workers' mobilization
	11. Shortage of equipment	Environment & Safety	26. Volume of debris
	12. Inflation of labor wages		27. Environmental/safety issues prior to execution of the project
	13. Availability level of on-site infrastructure		28. Work suspension through execution of the project
	14. On-site accommodation level for staff	Legal	29. Regulatory requirement
	15. Shortage of suppliers	Local	30. Availability of required temporary pathways

4.2. Survey development and pilot testing

A 46-question survey was developed, based on the potential list of PRTs (Table 2). It consisted of three types of questions, namely continuous, seven-point Likert scale, and binary. Questions regarding the respondents' demographic information were also included. Several of the questions from the survey are shown in Figure 2.

I. How many numbers of main/trunk lines did the selected reconstruction project consist of? (Main/trunk line refers to the primary linkage serving main arteries of interaction and commerce in transportation networks.)

Number: ________________

II. What was the total lengths of the selected reconstruction project?

Number: ________________

Fig. 2. Two sample questions of the survey

The survey was pilot tested and modified based on the responses.

4.3. Survey distribution

Specific criteria were established for those who would be invited to participate in the survey. One of them was that they must have experience in working on and/or monitoring the reconstruction of a transportation project. A list of potential participants was prepared and included program managers, directors, project managers, and engineers from different governmental and private agencies, state transportation agencies, and departments of transportation etc. They were contacted through email, and the surveys were distributed to them via electronic media after receiving a positive response. After multiple follow-up emails, 30 completed responses were collected.

5. Descriptive analysis

5.1. Demographic information

The demographic information of the survey respondents is presented in Table 3, which shows that about 70% of the respondents had more than 20 years of work experience, approximately 25% of them were program managers or directors, and the rest were project managers or engineers. All of the respondents were involved with the owner stakeholders.

Table 3. Demographic information of respondents

Years of Experience	Percentage (%)	Current Role in the Company	Percentage (%)
Less than 10 years	12.5%	Program Manager	8%
Between 10 and 20 years	21%	Director	17%
Between 21 and 30 years	37.5%	Project Manager	30%
More than 30 years	29%	Engineer	45%

5.2. Comparison of projects' baseline schedules and actual time

Box plots were used to demonstrate the baseline schedule and actual time of the selected reconstruction projects for which the respondents provided information, and the results are presented in Figure 3. It was observed that the maximum values of the projects' actual time and baseline schedules were about 90 months and 60 months, respectively. The medians of actual time and baseline schedules were roughly 12 months and 20 months, respectively. Both of the results demonstrated the marked differences in the baseline schedules and the actual time of the selected reconstruction projects.

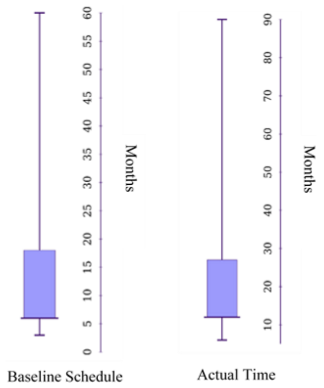

Fig. 3. Comparison of projects' baseline schedules and actual time

6. Quantitative analysis

6.1. Identifying significant PRTs affecting projects' schedule performance

The survey was constructed using three types of data: 1) continuous, 2) seven-point Likert scale, and 3) binary. Three types of statistical tests, the two-sample t-test, 2) Kruskal-Wallis test, and 3) Chi-squared test were used for the types of data, respectively. The P-values that identified the PRTs that most significantly affect the schedule performance of post-hurricane reconstruction of transportation infrastructures are presented in Table 4 and show that 20 out of 30 identified PRTs were statistically significant.

Table 4. Results of significant PRTs affecting reconstruction schedule

Category	List of PRTs	*P*-Value
Physical Characteristics	PRT1. Number of main/truck lines	0.022**
	PRT2. Total length	0.850
	PRT3. Level of complexity	0.042**
	PRT4. Distance from highly populated area	0.078*
Damaging Level	PRT5. Level of damage	0.011**
	PRT6. Level of traffic disturbance	0.061*
Resource	PRT7. Shortage of experts	0.011**
	PRT8. Shortage of field laborers	0.012**
	PRT9. Productivity level of contractors	0.025**
	PRT10. Shortage of materials	0.037**
	PRT11. Shortage of equipment	0.017**
	PRT12. Inflation of labor wages	0.290
	PRT13. Availability level of on-site infrastructure	0.750
	PRT14. On-site accommodation level for staff	0.410

	PRT15. Shortage of suppliers	0.020**
Quality	PRT16. Quality issues of materials	0.081*
	PRT17. Quality issues of equipment	0.021**
Project Management	PRT18. Frequency level of logistics/management issues	0.013**
	PRT19. Quality of on-site inspections	0.032**
	PRT20. Frequency of on-site inspections	0.422
	PRT21. Information management	0.068*
	PRT22. Pace of decision-making process	0.041**
	PRT23. Implementation level of risk management	0.082*
	PRT24. Coordination	0.046**
	PRT25. Pace of workers' mobilization	0.258
Environment & Safety	PRT26. Volume of debris	0.124
	PRT27. Environmental/safety issues prior to execution of the project	0.274
	PRT28. Work suspension through execution of the project	0.001**
Legal	PRT29. Regulatory requirement	0.205
Local	PRT30. Availability of required temporary pathways	0.163

**denotes significant differences with 95% confidence
* denotes significant differences with 90% confidence

6.2. Interpretation of the results

The physical characteristics of a project have a significant impact on the project schedule. Table 4 shows that three PRTs, namely PRT-1 (high number of main lines), PRT-3 (level of complexity), and PRT-4 (distance from highly populated area) have significant p-values because they often result in complex plans and schedules. In addition, their presence might increase the number of discussions between the stakeholders and cause delays.

The level of damage also affects the reconstruction project schedule appreciably. For instance, a highway or bridge with a high level of damage creates a major traffic disturbance, and the delays that are inherent in providing a temporary route for the disrupted traffic frequently cause delays that translate into schedule overruns for the project.

A lack of resources is one of the major causes of the failure of transportation reconstruction projects. Table 4 illustrates that shortages of experts, laborers, materials, equipment, and suppliers affect the reconstruction schedule. The contractors' level of productivity is also a major factor in whether a project will be completed on time, as all reconstruction projects after natural disasters are complicated, unexpected, and need a quick turnaround.

Quality is another important category in controlling the schedule of reconstruction projects, and unexpected issues with the quality of materials (PRT16) and/or equipment (PRT17) can cause delays.

The time and budget constraints of reconstruction projects require that they be efficiently managed. Ineffective coordination (PRT-24) means lack of alignment among project organizations and/or team members. The process of communication can be time-consuming and affect the schedule performance.

The environment and safety, legal, and local categories have less impact on the duration of reconstruction projects of transportation infrastructures, but if the work has to be suspended because of issues related to any of these categories, it negatively impacts the schedule of the project.

7. Conclusion

Transportation infrastructures are highly affected by natural disasters, especially by hurricanes, and the recovery pace of the affected community depends largely on their reconstruction. For this reason, it is necessary to ensure the completion of the reconstruction of transportation infrastructures after a disaster within the estimated time and budget. Unfortunately, it is not rare for such projects to be prolonged for various reasons, which adversely affects the overall recovery of the community. The existing literature lacks lists of significant factors that affect the reconstruction schedule of transportation infrastructures after natural disasters; therefore, the aim of this study was to identify those critical factors To this end, a survey was developed and distributed to a select group of experts, and after the 30 responses were collected and statistically analysed, it was found that the possibility of schedule overruns increases with an increase in the complexity and damage levels of the projects. The shortages of resources (experts, suppliers, laborers, materials, and equipment) that accompany a hurricane reduce productivity and increase the estimated time of completion. The result of this study will help practitioners and engineers take the steps that are necessary to complete reconstruction projects within the estimated schedule.

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