A Damage-Based Analysis of Rework in Reconstruction of Infrastructure Projects Due to Natural Disasters

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Abstract

The number of reworks and their corresponding costs are usually much higher for reconstruction projects than for construction projects. Even though a significant amount of research has been conducted to identify the causes and factors of rework, none have been based on post-disaster reconstruction. Therefore, it is the aim of this study, is to identify and categorize the critical factors that initiate the rework and affect the cost of post-disaster reconstruction of transportation infrastructures (PRTs). To fulfill that goal, a survey of 46 questions was developed and distributed. Thirty (30) completed responses were collected from a group of respondents who were owners, program managers, project managers, and engineers with experience in working on a reconstruction project. The responses were analyzed statistically, and it was found that when the reconstruction of a transportation project is complex, the number and cost of reworks rise significantly. It was also found that the number of reworks is directly related to the level of damage to the infrastructure, which means that skilled and experienced project managers must be assigned to the project so that the fast decision-making process can be ensured to avoid the excessive amount of reworks. The findings of this study will help decision-makers and program managers prevent undue expenses and delays in the restoration of damaged infrastructure after natural disasters and hurricanes.

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1. Introduction

Rework is one of the major causes of cost and schedule overruns of construction projects [1, 2, 3, 4]. In 2011, research was conducted by the Construction Industry Institute, and it was found that the direct cost of reworks of a construction project reach 20% of the project's contracted amount [5]. Shahparvari and Fong [6] found that the cost of rework, which is different for each project, can be up to 70% of the total project cost. Hence, the cost of rework is considered an indicator of the execution performance of a project [7, 8, 9]. Rework also acts as a catalyst in the reduction of organizational performance by demotivating the workers [10, 11]. Even though rework affects different projects in different ways [12], the sources of the reworks with substantial impacts are not drastically different [13].

Post-disaster reconstruction projects often suffer from unwanted and unprecedented reworks [14]. The number of reworks, as well as the cost of rework, is usually much higher in reconstruction projects compared to construction projects [7, 15]. The construction industry is one of the industries with most

uncertainties in the world [16], and reconstruction projects are even riskier, as they encompass additional safety requirements and time, cost, and space limitations [17]. The cost and time-sensitive nature of the projects require that they be performed in such a way that the negative impacts on the budget and schedule can be avoided [18, 19, 20]. Reworks in post-disaster reconstruction of transportation infrastructures is especially harmful, as it not only slows down the recovery of the damaged transportation infrastructure, but also indirectly slows down the overall recovery of the community [21]. Despite a significant number of researches in the literature regarding the causes and factors of reworks in the construction industry [22, 23], there are few such studies based on post-disaster reconstruction.

The aim of this study is to identify and categorize the critical factors that initiate reworks and affect their cost in the post-disaster reconstruction of transportation infrastructures (PRTs). To fulfill the goals of this study, several research objectives were formulated: i) identify potential PRTs leading to rework in post-disaster reconstruction projects of transportation infrastructures, ii) determine significant PRTs leading to rework of reconstruction projects, and iii) determine significant PRTs affecting the cost of reworks associated with the damage level of the infrastructure. The findings of this study will help decision-makers and program managers prevent undue expenses and delays in the restoration of damaged infrastructures after natural disasters, and hurricanes in particular.

2. Literature review

Almost every community suffers from casualties and losses due to natural disasters at some time [24, 25] and there has been an increase in the number of natural disasters over the last couple of decades [26, 27]. One of the most devastating natural disasters are hurricanes, which are increasing in intensity and frequency [28]. On average, every year, the United States of America suffers from two hurricanes [29]. They disrupt community life by causing physical, psychological, and environmental distress, especially when the society is not sufficiently equipped to handle the disaster [30]. For example, Hurricane Katrina in New Orleans caused \$1845 billion of damage, and Hurricane Rita caused \$120 billion of damage in 2005 in areas surrounding the Gulf of Mexico [31, 32].

These disasters usually cause the greatest damage to the transportation infrastructures, which makes the reconstruction costly and time-consuming [30, 33, 34]. Functioning transportation systems are a prerequisite for the mobility of the public and for economic growth [35]. A damaged transportation system cannot facilitate the usual traffic flow, hinders emergency response, causes indirect losses, and increases the sufferings of the people in the affected community [36, 37, 38]. In 1991, the Northridge disaster disrupted critical highways in the Los Angeles area, and a ripple effect caused the closure of several parts of Interstate 10 and resulted in \$1 million of economic loss each day for several days [39]. To avoid these unwanted and unforeseen economic losses and human suffering, it is vital that damaged transportation infrastructures be reconstructed as soon after the disaster as possible [40].

Resource constraints are a common side effect of post-disasters [41], and the shortages can have a major impact on the recovery of transportation infrastructures [27, 42, 43]. A project can be identified as successful when the completion time and cost are within the initially estimated schedule and budget, respectively [44, 45]. However, reconstruction projects are not only complex, but also have a chaotic and dynamic nature that can cause unpredictable changes in the middle of a project and require reworks [46, 47, 48]. Aljailawi and Shariatmadar [49] defined rework as efforts that are unnecessary and only required when the activity was not done properly the first time. The number of reworks can highly increase the cost and time of the project [18]. Conversely, the reduction of reworks ensures sustainable development, as less rework means that fewer materials are wasted [49]. Amaratunga et al. [50] found that reducing reworks can highly improve the performance of reconstruction projects.

In a nutshell, the success of post-disaster reconstruction depends upon the project being on time, within budget, and with the least possible number of reworks. However, many researchers have identified factors that might cause cost overruns, schedule overruns, and an extensive number of reworks, and a list of them is presented in Table 1.

Table 1. Challenges that affect cost, schedule, and number of reworks of a post-disaster reconstruction project

Challenge	Previous Study
Resources are not delivered within the deadline	[51]
Not having sufficient funds	[52]
Faulty assessment of the situation	[53]
Lack of communication and disorder in coordination	[54]
Faulty design	[55]
Transportation	[56]
Difficulty in arranging temporary paths	[57]
Faulty assessment of the level of damage	[58]
Shortage of laborers	[18]
Shortage of materials	[18]
Inability to make impromptu decisions	[59]
Inexpert inspectors	[60, 61]

3. Research methodology

The four-step methodology shown in Figure 1 was adopted for this study. The first step was focused on a review of the existing literature. A preliminary search via popular search engines resulted in 500 articles. The secondary screening process was conducted by scrutinizing the titles and abstracts of the papers, and 89 articles were shortlisted. The shortlisted articles were studied and, based on the information gathered, a list of 30 potential PRTs was prepared. In the second step, a survey was developed and distributed after pilot testing, and 30 completed responses were collected. In the third step, a descriptive analysis of the cost of the reworks and level damage of the infrastructure was conducted. In the last step, the data were analyzed quantitatively and the significant PRTs were identified.

Fig. 1. Research methodology

4. Data collection

4.1. Development of the list of PRTs

A keyword search method through popular search engines like Google Scholar, JSTOR, ProQuest, etc. resulted in the collection of approximately 500 scholarly articles. The titles and abstracts of the collection were scrutinized, and 89 articles that were considered the most relevant were shortlisted. The shortlisted articles were studied thoroughly, and pertinent information was entered into a database that was used, along with the expertise and experience of the authors, to prepare a list of 30 potential PRTs. Table 2 shows the identified PRTs.

Table 2. list of potential PRTs

List of PRTs	List of PRTs
PRT1. Number of main/truck lines	PRT16. Quality issues of materials
PRT2. Total length	PRT17. Quality issues of equipment
PRT3. Level of complexity	PRT18. Frequency level of logistics management issues
PRT4. Distance from highly populated area	PRT19. Quality of on-site inspections
PRT5. Level of damage	PRT20. Frequency of on-site inspections
PRT6. Level of traffic disturbance	PRT21. Information management
PRT7. Shortage of experts	PRT22. Pace of decision-making process
PRT8. Shortage of field laborers	PRT23. Implementation level of risk management
PRT9. Productivity level of contractors	PRT24. Coordination
PRT10. Shortage of materials	PRT25. Pace of workers' mobilization
PRT11. Shortage of equipment	PRT26. Volume of debris
PRT12. Inflation of labor wages	PRT27. Environmental/safety issues prior to execution of the project
PRT13. Availability level of on-site infrastructure	PRT28. Work suspension through execution of the project
PRT14. On-site accommodation level for staff	PRT29. Regulatory requirement
PRT15. Shortage of supplier	PRT30. Availability of required temporary pathways

4.2. Survey development, distribution, and collection

After identifying the potential PRTs, a structured survey was constructed that converted each PRT into a question. The participants were also asked to provide demographic information and to name a post-disaster transportation reconstruction project that they had worked on. The survey consisted of 46 questions of three kinds: i) continuous questions, ii) seven-point Likert scale questions, and iii) binary questions. Two sample questions of the survey are presented in Figure 2.

34. Was construction of the selected project suspended due to intolerable weather conditions (e.g. extreme heat and cold weather)?

☐ Yes

☐ No

If your answer to the previous question is "Yes", please answer the following questions:

35. Approximately, what was the duration of work suspension through construction of the selected project?

Fig. 2. Sample survey questions

The survey was pilot tested to determine its suitability for the participants, and it was modified, based on the responses of those participating in the testing.

A list was developed of potential respondents who were owners, project managers, program managers, and engineers. The respondents were contacted by email, and upon their agreement the survey was sent to them electronically. After several follow-up emails, 30 completed responses were collected.

5. Descriptive analysis

5.1. Based on the cost of the project and the cost of rework

Table 3 shows the minimum, mean, and maximum values for the cost of the projects and the cost of the reworks. The mean and maximum cost values of the reworks were roughly \$270,000 and \$1 million, respectively.

Table 7: Descriptive Data Analysis

		Minimum	Mean	Maximum	Standard Deviation
Cost	Baseline Budget	\$300K	\$22,930K	\$100,000K	\$33,200K
	Actual Cost	\$500K	\$36,540K	\$150,000K	\$53,110K
Rework	Cost	\$50K	\$264K	\$1,000K	\$361K

5.2. Based on the level of damage

In response to a query about the level of damage sustained by the infrastructure that the survey respondents were involved with following a natural disaster, they revealed almost 30% of the projects had infrastructures that were damaged more than 80% and around 20% of the projects had infrastructures that were damaged less than 40%.

6. Quantitative analysis

6.1. Determination of significant PRTs leading to rework of reconstruction projects

The PRTs that significantly lead to reworks in reconstruction projects are shown in Table 4. The two-sample t-test, Kruskal-Wallis, and Chi-squared test were performed according to the appropriate type of data. To avoid any bias created by including large projects in the results, the cost of the issued rework was normalized based on project size. To calculate the normalized cost of rework for any project, the cost of the rework was divided by the baseline budget for the construction phase. These costs were recorded and used for the remainder of the analyses conducted for this study. Table 4 presents that 22 PRTs were recorded as significant in deriving reworks in reconstruction projects.

Table 4. Results of significant PRTs leading to rework in reconstruction projects

Category	List of PRTs	P-Value
Physical Characteristics	PRT1. Number of main/truck lines	0.021**
	PRT2. Total length	0.256
	PRT3. Level of complexity	0.062*
	PRT4. Distance from highly populated area	0.011**
Damaging Level	PRT5. Level of damage	0.018**
	PRT6. Level of traffic disturbance	0.637
Resource	PRT7. Shortage of experts	0.033**
	PRT8. Shortage of field laborers	0.014**
	PRT9. Productivity of contractors	0.072*
	PRT10. Shortage of materials	0.054*
	PRT11. Shortage of equipment	0.036**
	PRT12. Inflation of labor wages	0.333
	PRT13. Availability of on-site infrastructure	0.044*
	PRT14. On-site accommodation level for staff	0.078*
	PRT15. Productivity of suppliers	0.002**
Quality	PRT16. Quality issues of materials	0.029**
	PRT17. Quality issues of equipment	0.066*
Project Management	PRT18. Number of logistics management issues	0.088*
	PRT19. Quality of on-site inspections	0.034**
	PRT20. Number of on-site inspections	0.019**
	PRT21. Information management	0.093*
	PRT22. Pace of decision-making process	0.080*
	PRT23. Implementation level of risk management	0.019**
	PRT24. Coordination	0.077*
	PRT25. Pace of workers' mobilization	0.155
Environment & Safety	PRT26. Volume of debris	0.474
	PRT27. Environmental/safety issues prior to execution of the project	0.212
Legal	PRT28. Work suspension through execution of the project	0.652
	PRT29. Regulatory requirement	0.001**
Local	PRT30. Availability of required temporary pathways	0.177

** denotes significant differences with 95% confidence

* denotes significant differences with 90% confidence

As presented in Table 4, the lack of frequent on-site inspections (PRT-20, belonging to the category of project management) and low quality of on-site inspections (PRT-19, belonging to the category of project management) leads to decreased productivity and waste of limited post-hurricane resources. The lack of adequate quality and sufficient quantity of on-site inspections results in inadequate documentation and records and often causes duplications of efforts and an increase in the number and cost of reworks.

Table 4 indicates that when the reconstruction of a transportation project is complex (PRT-3, belonging to physical characteristics), skilled and experienced site laborers and project managers need to be involved in

the project. After a disaster, clients are usually faced with a shortage of human resources; therefore, when the reconstruction project is complex, the probability of reworks being needed might remarkably increase.

6.2. Descriptive comparison of PRTs affecting rework of reconstruction projects

A descriptive comparison of the mean values of reconstruction projects with low costs of reworks and high costs of reworks associated with continuous data are shown in Table 5. The mean values of PRTs 1, 4, and 5 are significantly different. For instance, the average distance of a project's location from a highly populated area (PRT-4) in a project with a low cost of rework (12.5 miles) is very different from the same project with a high cost of rework (30.5 miles). The mean of the damage level for reconstruction projects with a low cost of rework was 50%, while the same average for projects with a high cost of rework was 70%. Therefore, it was concluded from Table 5 that reconstruction projects with poor performance are more complicated than those with good performance.

Table 5. Comparative analysis of PRTs affecting cost of rework – continuous data

List of PRTs	Average	
	Low Cost of Rework	High Cost of Rework
PRT1. Number of main/truck lines	9	3
PRT4. Distance from highly populated area	12.5 mi	30.5 mi
PRT5. Level of damage	50%	70%

6.3. Determination of significant PRTs leading to rework of reconstruction projects for low- and high-level damage

In this step, the PRTs that significantly affect the cost of reworks associated with the two groups (highly damaged and low-level damage) were statistically determined and presented (Table 6). Three types of statistical analysis methods, the two-sample t-test, Chi-Square, and Kruskal-Wallis test were adopted according to the type of data. Table 6 indicates that 24 of the 29 PRTs were determined statistically significant for highly damaged reconstruction projects, and 20 PRTs were recorded as statistically significant for low-level damaged reconstruction projects.

As presented in Table 6, the availability of PRT-1 (number of main lines), PRT-3 (level of complexity), and PRT-4 (distance from the highly populated area), belonging to the category of physical characteristics, make reconstruction projects more complicated and increase the number of uncertainties and risks. These issues lead to suspension of the projects, frustrate the team members, and foster low productivity, thereby increasing the number and cost of the reworks.

Information management (PRT-21) also plays a critical role in post-hurricane reconstruction projects by tracking projects' resources, improving budgeting and cost analyses, and mitigating risks. Lack of information management seriously affects the quality of project management and results in more reworks.

Table 6. Results of significant PRTs affecting rework regarding damage level in reconstruction projects

Category	List of PRTs	P-Value	
		Highly Damaged	Low Level Damaged
Physical Characteristics	PRT1. Number of main/truck lines	0.029**	0.025**
	PRT2. Total length	0.254	0.359
	PRT3. Level of complexity	0.092*	0.083*
	PRT4. Distance from highly populated area	0.028**	0.013**
Damaging Level	PRT6. Level of traffic disturbance	0.634	0.179
Resource	PRT7. Shortage of experts	0.011**	0.016**
	PRT8. Shortage of field laborers	0.091*	0.055*
	PRT9. Productivity of contractors	0.071*	0.059*
	PRT10. Shortage of materials	0.020**	0.089*
	PRT11. Shortage of equipment	0.014*	0.001**
	PRT12. Inflation of labor wages	0.199	0.435
	PRT13. Availability of on-site infrastructure	0.007**	0.031**

	PRT14. On-site accommodation level for staff	0.088*	0.633
	PRT15. Productivity of suppliers	0.059*	0.074*
Quality	PRT16. Quality issues of materials	0.016**	0.027**
	PRT17. Quality issues of equipment	0.037**	0.015**
Project Management	PRT18. Number of logistics management issues	0.056*	0.072*
	PRT19. Quality of on-site inspections	0.066*	0.028**
	PRT20. Number of on-site inspections	0.080*	0.017**
	PRT21. Information management	0.069*	0.077*
	PRT22. Pace of decision-making process	0.022**	0.759
	PRT23. Implementation level of risk management	0.082*	0.032**
	PRT24. Coordination	0.022**	0.075*
	PRT25. Pace of workers' mobilization	0.058*	0.153
Environment & Safety	PRT26. Volume of debris	0.195	0.174
	PRT27. Environmental/safety issues prior to execution of the project	0.647	0.357
	PRT28. Work suspension through execution of the project	0.019**	0.754
Legal	PRT29. Regulatory requirements	0.033**	0.001**
Local	PRT30. Availability of required temporary pathways	0.391	0.351

** denotes significant differences with 95% confidence

* denotes significant differences with 90% confidence

7. Conclusion

The number of reworks has an appreciable negative impact on the construction, as well as post-disaster reconstruction, of transportation infrastructure systems. Even though there are a significant number of researches in the literature that identify the sources and factors of reworks in construction projects, few identify the factors that affect the reworks of post-disaster reconstruction. Therefore, this study aimed to identify and categorize the factors that lead to reworks in the post-disaster reconstruction of transportation infrastructures. For this purpose, a survey was developed, and 30 completed surveys were collected. The survey result was analyzed both qualitatively and quantitatively and revealed that when the reconstruction of a transportation project is complex, the number and cost of reworks is high, and skilled and experienced project managers must be assigned so that a rapid decision-making process can be ensured. It was also found that the number of reworks is directly correlated with the level of damage to the infrastructures. When the level of damage is comparatively high, skilled site laborers and project managers need to be involved in the project to avoid an excessive number of reworks. The findings of this study will help decision-makers and program managers prevent undue expenses and delays in the restoration of damaged infrastructures after natural disasters, particularly hurricanes.

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