Cost and Time Impacts of Reworks in Building a Reinforced Concrete Structure

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ABSTRACT

In construction industry, rework is one of the major factors that affect the success of a construction project. It causes to decrease the quality and productivity, and increases the cost and time of construction. Rework commonly happens due to insufficient supervision, poor workmanship, wrong or defective materials, etc.

This research intends to determine the cost of waste and time delay due to reworks in the construction of reinforced concrete structure, to investigate the factors affecting the rework such as contractors, owners, and consultants. Also in this research the rework items, their frequencies, their correlation, and their impact on cost of waste and time delay were investigated. A case study project consisted of three 8-storeys buildings was observed and studied, and a questionnaire survey was undertaken among 22 construction projects to collect data. The case study and questionnaire survey findings revealed that, the reworks influenced the cost by 1.85% and 2.1% of construction cost respectively. Also the findings indicated that, the time delay of rework in case study and survey was 4.1% and 5.18% of construction duration respectively. It was obtained that, the major rework items affecting the cost were: 1- allocating inappropriate concrete materials, 2- changing the designed steel bar diameters due to unavailability, and 3- forming cold joint due to mismanagement of concrete delivering to the site. The major rework items that affecting the delay were: 1- collapsing excavation walls, 2- over excavation, and 3- falling formwork materials from top storeys that causes damage to them.

Keywords: rework, cost, time, rework factors, reinforced concrete structure

ÖZ

İnşaat sektöründe hata tamiri, inşaat projesinin başarısını etkileyen en önemli faktörlerden biridir. Hata tamiri, kalite ve verimliliğin azalmasına ve maliyet ile sürenin artmasına neden olur ve çoğunlukla yetersiz denetim, kötü işçilik ve yanlış ya da kusurlu malzeme kullanımından dolayı meydana gelir.

Bu araştırma, maliyet açısından, müteahhitler, mal sahipleri ve müşavirler gibi hata oluşmasını etkileyen faktörleri araştırarak, betonarme binaların yapımında hata tamirinden dolayı ortaya çıkan maliyet kaybını ve süre gecikmesini belirlemeyi amaçlar. Ayrıca bu araştırmada, hata tamir nedenleri, sıklıkları, birbirleriyle olan ilişkileri ve maliyet kaybı ile süre gecikmesi üzerindeki etkileri araştırılmıştır. Bu araştırmada, 3 tane 8 katlı binayı içeren örnek çalışma projesi yerinde incelenerek çalışıldı ve bilgi toplamak için 22 inşaat projesi arasında anket yapıldı. Örnek yerinde inceleme çalışması ve anket sonuçları, hata tamirinden dolayı etkilenen maliyetin, inşaat maliyetinin sırası ile, %1.85'i ve %2.1'i kadar olduğunu ve ayrıca, örnek yerinde inceleme çalışının ve anketten elde edilen süre gecikme etkilerinin, inşaat süresinin sırası ile, % 4.1'i ve %5.18'i kadar olduğunu ortaya çıkardı. Maliyeti etkileyen önemli hata tamir nedenleri şunlardır: 1- uygun olmayan beton malzemelerinin tahsis edilmesi, 2- demir çaplarının değiştirilmesi, ve 3- şantiyeye yapılan beton dağıtımının kötü yönetiminden dolayı soğuk derzlerin oluşmasıdır. Süre gecikmesini etkileyen önemli hata tamir nedenleri ise şunlardır: 1- kazı işlerinde olan toprak çökmeleri, 2- fazla yapılan kazı işleri, ve 3- yüksek katlardan düşen kalıp malzemelerinin zarar görmesi olarak elde edildi.

Anahtar kelimeler: hata tamiri, maliyeti, süresi, nedenleri, betonarme yapı.

To My Dear Family

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LIST OF ABBREVIATIONS

BRE	Building Research Establishment
CIDA	Construction Industry Development Agency
CIDB	Construction Industry Development Board
CII	Construction Industry Institute
COAA	Construction Owners Association of Alberta
NEDO	National Economic Development Office

Chapter 1

INTRODUCTION

1.1 Background

The importance of construction industry is approved in all communities. It is one of the major industries in the economic growth and civilization. A huge amount of money, time and energy consuming in this part indicate the important role of this industry. Construction industry not only includes buildings construction, but also covers roads, bridges, dams and skyscrapers construction.

Construction methods have been changed enormously since human started to construct shelters. There was not adequate design information and people had to do everything by human force because there was no machine at that time. The methods of construction improved through thousands of years and new construction technologies emerged meanwhile. As technologies are improved nowadays, construction industry is getting automated and prefabrication method becomes very popular in many countries. Although the role of human in construction is decreased in recent years, still human has a major role, so mistakes are still exist.

In the process of construction, mistakes frequently occur and they lead to reworks in different stages of construction. In general, reworks and wastages are known as non-value adding symptoms that affect the productivity and performance in construction projects (Alwi et al., 2002) and probably the most complete definition of rework is provided by Ashford (1992) which defines rework as the procedure that is making an item to adjust with the original requirements by correction or completion. Rework may happen because of the lack of quality control, insufficient maintenance, using unskilled workers and inadequate tools, etc. The reworks sometimes are happening as demolishing and rebuilding and sometimes as requirement of extra works.

The most important effect of rework is on productivity and productivity influences cost, time, and quality within the construction project. According to Kazaz and Ulubeyli (2007), enhancement of productivity has many advantages such as reducing total cost and production duration, improving quality, increasing product market share, and increasing salaries and employment. Generally, productivity growth is the most important economic indicator through it fast living standard growth could be attained (Tucker, 2003).

During 1980s and 1990s most of the United States economy sectors showed growth in labor productivity, however the construction sector was the only sector which had noticeably decline in its labor productivity as shown in Figure 1.1. Labor productivity is defined as the output per working hour and is one of the best production efficiency indicators (Rojas and Aramvareekul, 2003).

Enshassi et al. (2007) identified 45 factors that negatively affect construction labor productivity. The first three items were: material shortage, lack of labor experience, and lack of labor surveillance. Rework was ranked as 11th most effective factor that affects the productivity of construction labor, negatively.

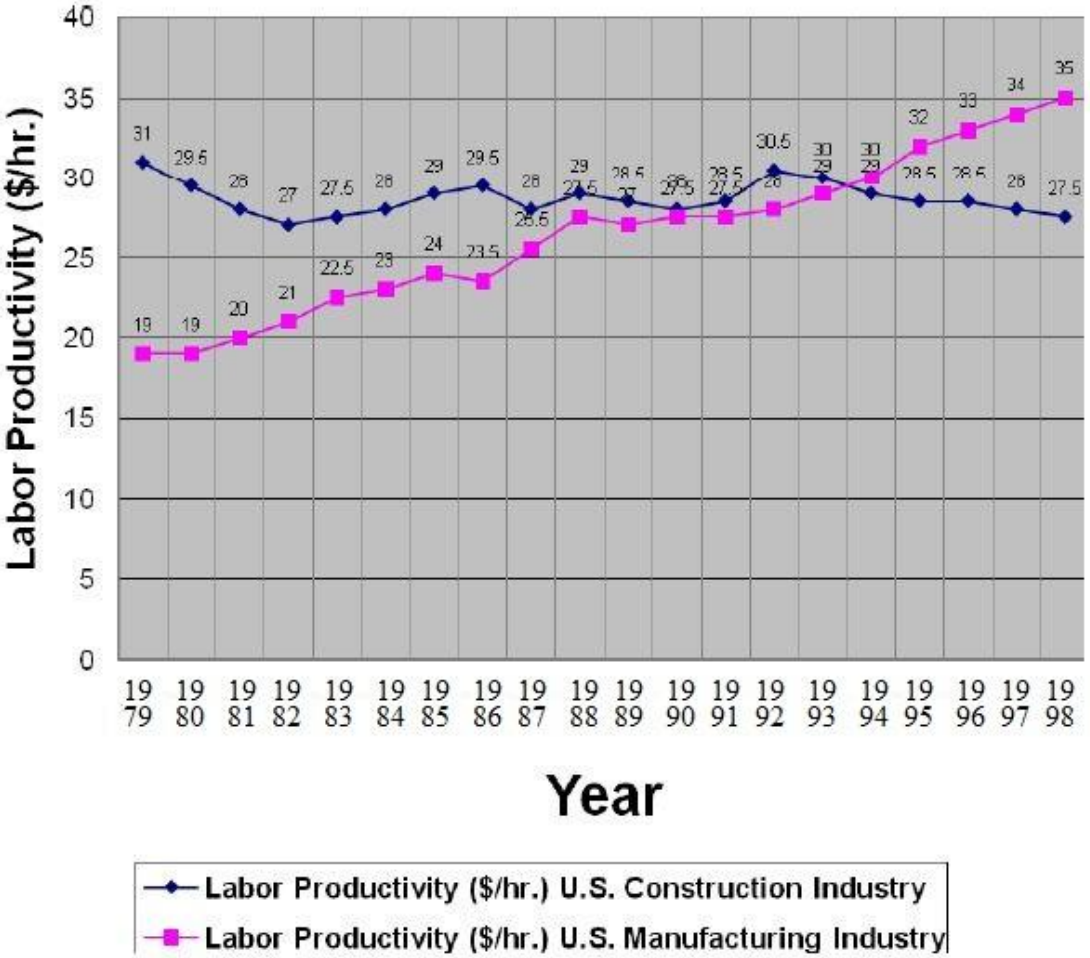


Figure 1.1. Labor productivity for construction and manufacturing industries in United States during 1979-1998 (Rojas and Aramvareekul, 2003)

In a comparative study of construction productivity problems in selected countries as listed in Table 1.1, Kaming et al. (1997) identified that lack of material, lack of equipment, interference, absenteeism, supervision delays, and rework were the problems of construction productivity. Interestingly, rework was ranked as the second problem in productivity in Indonesia and Nigeria, and the third problem in United Kingdom and United States of America.

Table 1.1. Factors negatively impacting construction productivity in selected countries (Kaming et al., 1997)

Productivity factors	Indonesia	Nigeria	UK	USA
	Rank	Rank	Rank	Rank
Lack of material	1	1	1	1
Lack of equipment	5	3	5	2
Interference	3	6	2	5
Absenteeism	4	5	6	6
Supervision delays	6	4	4	4
Rework	2	2	3	3

This study aims to investigate the impacts of reworks on cost and duration of construction of reinforced concrete structure, determining the share of factors (contractors, owners, and consultants) in cost of rework, and inquire the rework items in terms of their frequency and effect on cost and time. For this purpose, a project consisted of three 8-storeys building was observed and studied as a case study and a questionnaire survey was undertaken among 22 construction projects.

The rework cost in percentage of construction cost and the rework time in percentage of construction duration in case study project were estimated according to the observations and interviews, and the relevant cost and time in surveyed projects were calculated as the mean of rework costs and times of all projects. The share of each factor in rework cost was inquired in case study project, and in questionnaire survey it was measured as the average of each factor’s share among surveyed projects. 17 rework items were investigated in questionnaire survey and the frequency of each item was determined as the number of happening among 22 surveyed projects. The cost and time effects of each rework item were obtained by multiplying their importance index, which was gained from questionnaire, and frequency index.

1.2 Scopes and Objectives

The general objectives of this research are improving the construction quality and eliminating the cost of waste and time delay due to rework through the use of a case study and conducting a questionnaire survey and by focusing on rework as one of the major problems in construction industry. The specific scopes and objectives of this study are:

1. To identify the rework items that frequently happen in constructing reinforced concrete structure.
2. To investigate the rework items in terms of their frequency, and cost and time effect in constructing a reinforced concrete structure.
3. To specify the impact of rework on cost and duration of constructing reinforced concrete structure.
4. To determine the share of rework factors including contractors, owners, and consultants in rework cost.

1.3 Works Undertaken

These works were undertaken in this research:

1. A case study project was selected, construction activities were observed and interviews were taken.
2. Cost and time impact of rework and factor’s share in cost of rework in case study project were determined.
3. A questionnaire survey among 22 construction projects was undertaken.

4. The effects of rework on project cost and time, and the share of rework factors in cost of surveyed projects were prescribed and compared with the results of case study.
5. 17 rework items were investigated, their frequencies were ascertained, the correlations among rework items were found out through running a factor analysis, and cost and time effects of rework items were estimated by calculating their importance index.

1.4 Achievements

1. Among 17 investigated rework items, changing the designed steel bar diameters due to unavailability was the most frequent item, using inappropriate head for poker vibrators, and lacking reinforcement bars were ranked as second and third most frequent items.
2. The result of factor analysis showed that there were correlations among rework items and they could be categorized into 4 groups and each group represented one phase of constructing reinforced concrete structure which was: excavation, reinforcing, formwork, and concrete work.
3. Allocating inappropriate concrete materials, changing the designed steel bar diameters due to unavailability, and Forming cold joint due to mismanagement of concrete delivering to the site were the three most effective rework items in cost waste due to rework in order of their importance.
4. The three most effective rework items in time delay due to rework in order of their importance were: collapsing excavation walls, over excavation, and falling formwork materials from top storeys that causes damage to them.

5. Cost of rework in case study project was 1.85% of construction cost and the average of rework cost in 22 surveyed projects was almost 2.1% of the total cost of constructing a reinforced concrete structure.
6. Time delay due to rework was 4.1% of construction duration in case study project and it was around 5.18% as the average of time delay in surveyed projects.
7. Share of factors in rework cost was 46% for contractors, 37% for owners, and 17% for consultants in case study project. The relevant numbers in surveyed projects were around 49%, 31%, and 20% for contractors, owners, and consultants respectively.

1.5 Guide to Thesis

The second chapter of this thesis is literature review. In this chapter previous studies and researches related to rework are provided in 4 main sections. First section is rework definition, second section is about the rework causes, third section describes the rework impacts, and last section gives an overview.

The third chapter is methodology which explains the projects and the method of data collection, and comprises two main sections: case study and questionnaire.

The fourth chapter is data analysis and discussions. In this chapter, cost waste of rework comes first, time delay due to rework comes after, share of factors in rework cost comes next, and the analysis of rework items including their frequencies, their categories, and their effect on rework cost and time comes at the end.

Finally, the last chapter provides conclusion and recommendations.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter comprises four sections. First section defines and describes reworks in construction. Second section is rework causes which consists of different rework models and it is about the items that lead to the rework or rework causes. In the third section rework impacts in terms of cost and time delays on various construction projects in many countries are given, and the last section provides an overview of the literature.

2.2 Definition of Rework

Construction industry is wide and complicated. There are a lot of activities involved in this industry. Every construction project is unique and unpredictable so occurring of rework is unavoidable. Generally, reworks and wastages are known as non-value adding symptoms that affect the productivity and performance in construction projects (Alwi et al., 2002).

Rework has various interpretations and definitions. Terms include: "nonconformance" (Abdul-Rahman, 1995), "quality deviations" (Burati et al., 1992), "defects" (Hammarlund and Josephson, 1999) and "quality failures" (Barber et al., 2000). Rework can be described as unneeded effort of redoing an activity or operation that was enforced in a wrong way from the beginning (Love et al., 2000).

When a service or product does not meet the requirements of customer, rework occurs. Rework includes defects and it may include variations too. By the meaning of conformance, two major definition of rework can be provided. According to the definition of construction industry development agency, CIDA, (1995) rework is “doing something at least one extra time due to non-conformance to requirements”. The second definition describes rework as the procedure that making an item to adjust with the requisites by correction or completion (Ashford, 1992).

Many analysts have proposed that rework sometimes occurs because of complicated characteristics of the construction processes. There is a difference between engineering rework and construction rework. Engineering rework is a result of specification changes and owner scope, errors in design or contractual method and construction rework is caused by weak construction management policies or improper construction techniques (O’conner and Tucker, 1986). In case of rework sources, Devis et al. (1989) categorized the sources of rework as owner, designer, vender, transporter and, constructor. Likewise construction industry institute, CII, and Burati et al. (1992) mentioned 5 main fields of rework: design, transportation, manufacturing, construction, and feasibility.

Each of mentioned fields was subdivided by deviation type such as error, change, or negligence. These categorizations have different aspects from those suggested by Love et al. (1999 a, b) and Fayak et al. (2003) which propose that happening of rework is the consequence of ambiguity, poor communications and leadership, and inefficient managing.

CII (2001a) defined field rework as activities that should be done many times and activities which result in undoing the work that is already performed. Fayek et al. (2003) have followed and modified the CII's (2001a) definition of field rework and defined field rework as:

> Activities in the field that have to be done more than once in the field, or activities which remove work previously installed as part of the project regardless of source, where no change order has been issued and no change of scope has been identified by the owner.

Moreover, field rework is not:

- Changes in project scope.
- Design errors or changes that do not involved with field construction activities.
- Missing or additional scope because of designer or constructor errors (however cost associated with redoing parts of work that interface or incorporate with missing or additional scope does include in the rework).
- Fabricator errors that are occurred and corrected off site.
- Modular fabrication errors that are occurred and corrected off site.
- Fabrication errors that are occurred on site and do not affect direct field activities (i.e., that are rectified without interrupting the construction activities flow).

2.3 Rework Causes

To enhance the quality it is essential to realize the fundamental causes of rework as the major reason of rework existence or set of conditions that induce its happening in a process. A number of operations or activities which acting on inputs and transform them to the outputs make a process. A process may comprise value adding activities or non-value adding activities. Value adding activities commute materials or/and information towards the customer requirements and non-value adding activities take time, resource or require storage without adding value to the final output. Put differently, a non-value activity (such as rework) is waste (Love & Li, 1999).

Rework models contribute to better understanding of the body structure of rework. Characteristics of rework and rework factors are determined by the models. Various models of rework are represented in this section.

The conceptual model of rework that suggested by Love and Edwards (2004) is shown in the Figure 2.1. According to this model, project characteristics, organizational management practices and project management practices are the factors cause rework directly or indirectly, and they are also subdivided into more specific elements. Rework has effect on productivity and project performance. The two most important components of project performance are cost and time which are focused on in this thesis.

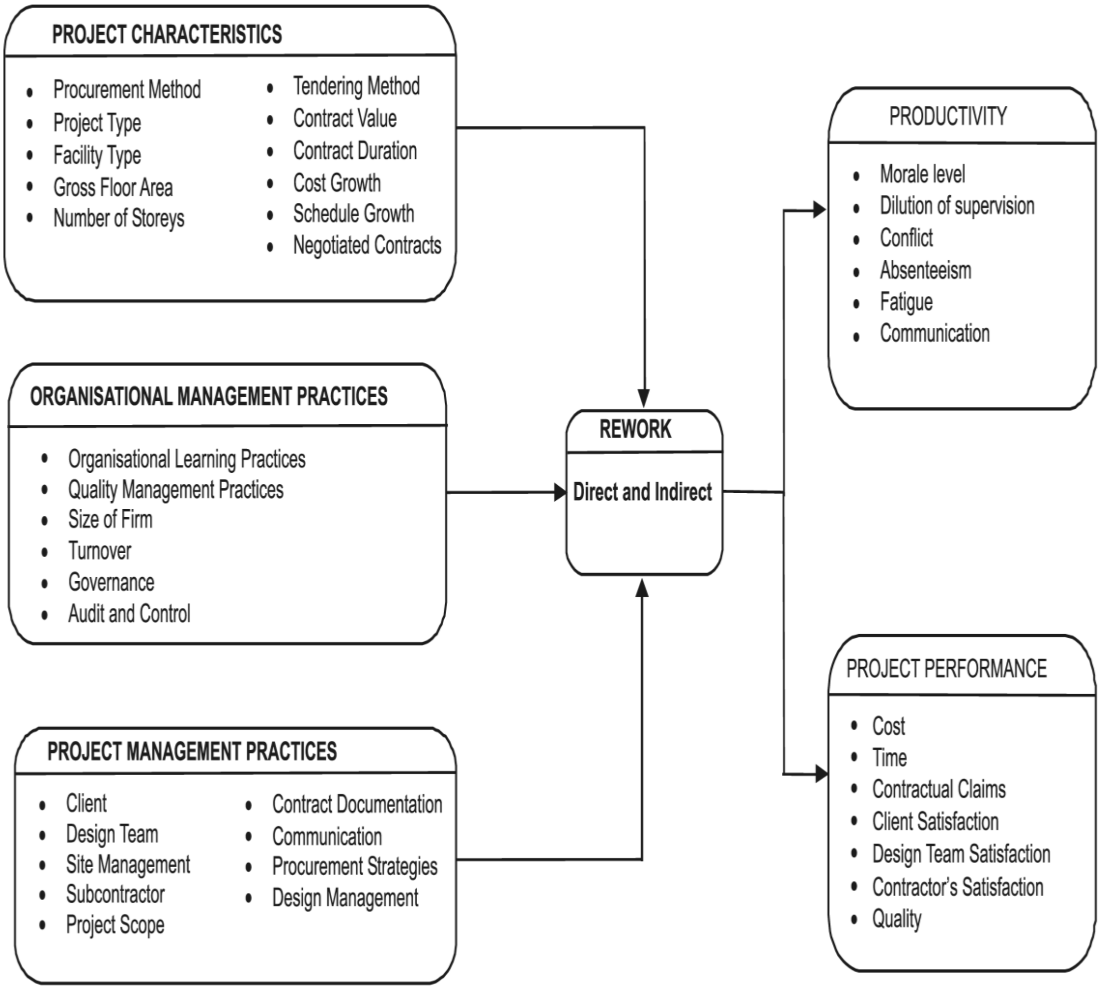


Figure 2.1. The conceptual model of rework (Love & Edwards, 2004)

COAA’s (Construction Owners Association of Alberta) rework cause classification which is also called fishbone diagram because of its shape is presented in Figure 2.2. It is technically known as Cause and Effect (CE) diagram and it was last updated on October 2002. This model classifies rework contributor to the following items:

- Human resource capability (excessive overtime, unclear instructions to workers, insufficient skill levels and inadequate supervision & job planning).
- Leadership and communications (lack of safety and quality assurance & control commitment, poor communications and lack of operations (end user) persons buy-in).

- Engineering & Reviews (errors and omissions, poor document control, scope changes and late design changes).
- Construction planning and scheduling (constructability problems, insufficient turnover and commissioning resourcing, late design input and unrealistic schedules) and,
- Material and equipment supply (materials not in right place when needed, prefabricate and construct not to project requirements, non-compliance with specification and untimely deliveries).

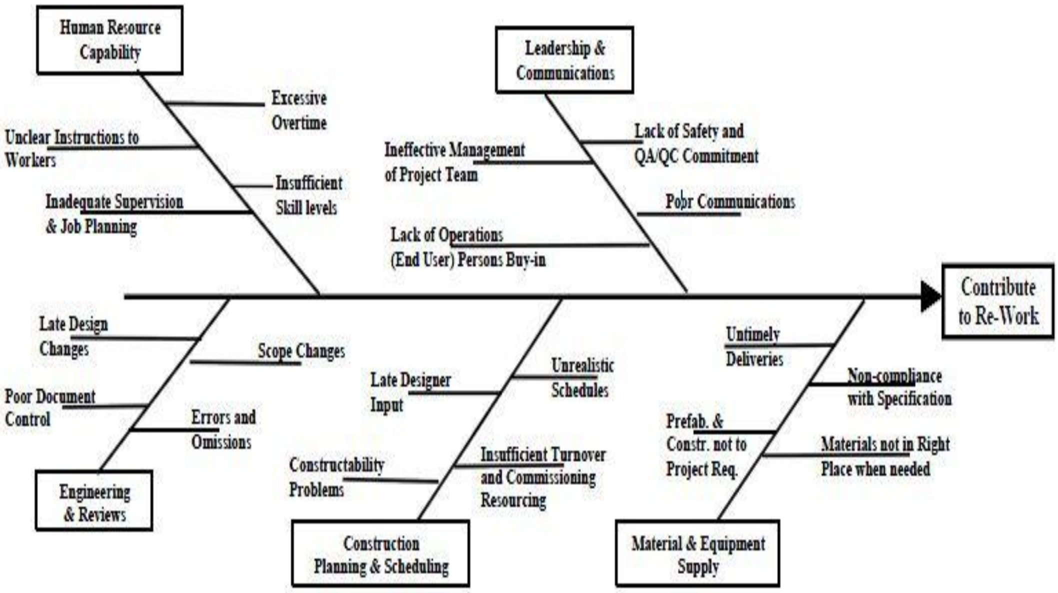


Figure 2.2. Rework classification (fishbone) (COAA, 2002)

Rework category model proposed by Wasfy (2010) is shown in Figure 2.3. It is composed of two major categories of factors cause rework, direct rework causes and indirect rework causes.

Direct rework causes are the factors that directly lead to rework occur and they consist of insufficient supervision, incompetent supervision, poor workmanship, wrong material, defective material, deviations from drawings, and errors and omissions in drawings.

Indirect rework causes refer to a group of causes that they do not cause rework themselves but they create the situations that will cause rework. These indirect rework causes are: selection of improper subcontractor, improper work protection, lack of coordination, and improper work sequencing.

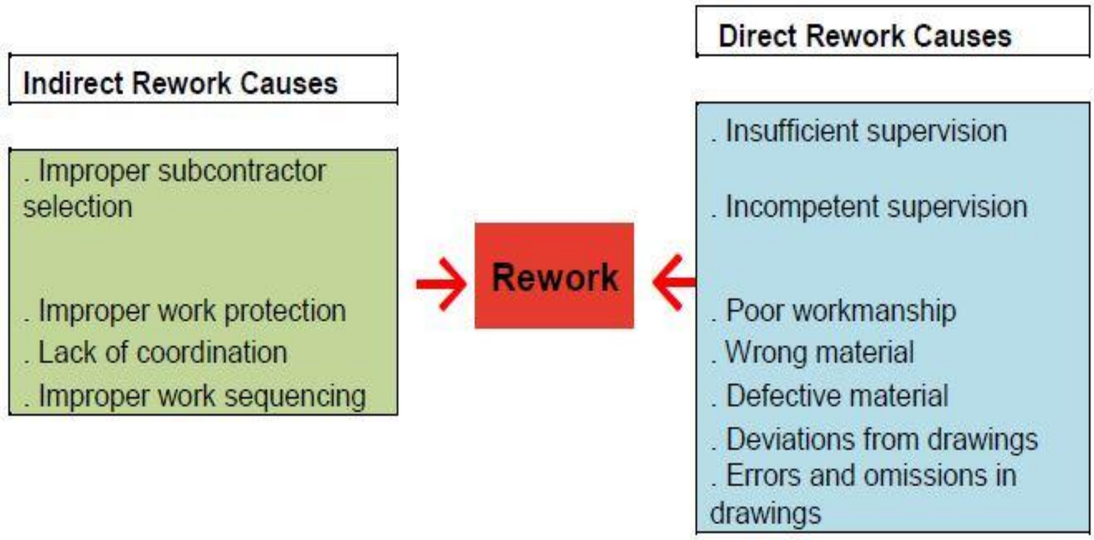


Figure 2.3. Rework categories (Wasfy, 2010)

According to the study of Evans and Lindsay (1996) and Mandal et al. (1998), a system of project can be classified and consisted of the below sub systems:

- Technical and operational
- Human resources
- Quality management

Love et al. (1999a) have developed a model to indicate the factors that could influence rework, by applying the mentioned categorization to construction. The model is illustrated in Figure 2.4.

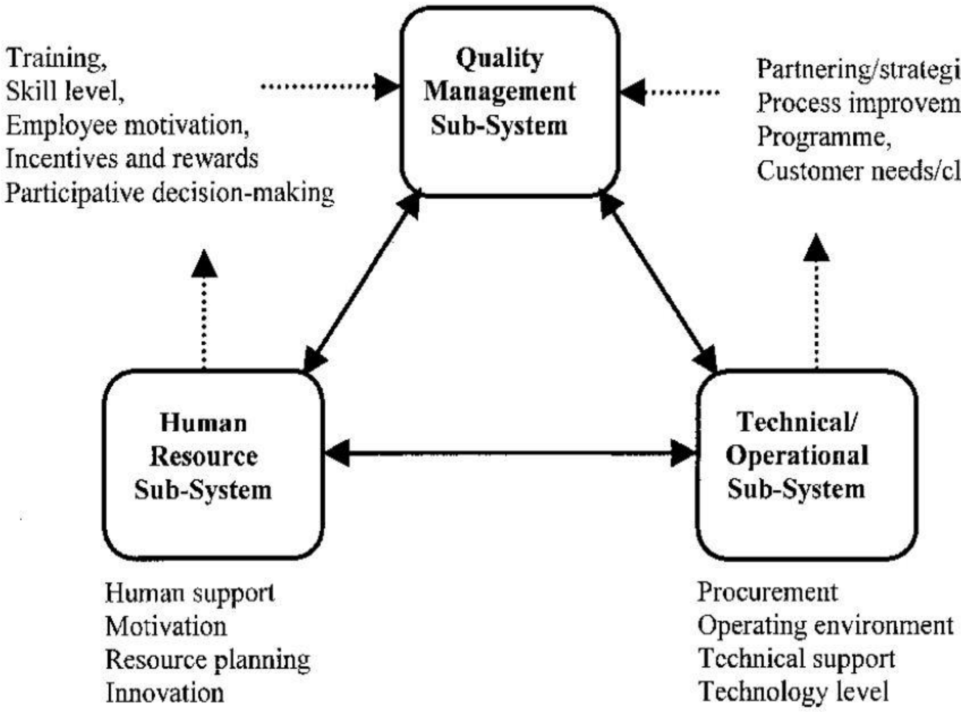


Figure 2.4. Interactions among the three sub-systems of a project
(Love et al., 1999a)

The major elements or items that have to be regarded in a sub-system of technical/operational are: operating environment, the contractual method, level of technology, and the technical support. These items determine the issues that are related to quality such as the enhancement of the process, partnering or strategic alignment, and realization of customer needs. The main factors of human resource subset of a system are: skill availability, manpower, procedures of communication, and employee morale. These elements influence the skill level, training needs, motivation of employee, and the process of making decisions in construction system and project organization both.

Love et al. (1999b) investigated on the relation of factors above, their internal mechanism, and how each factor affects other factor. They created diagrams for technical and operational influence, quality management sub-system influence, human resource subset influence, a causal model of rework in a project system and finally they created a conceptual rework model grounded on causal modeling concepts.

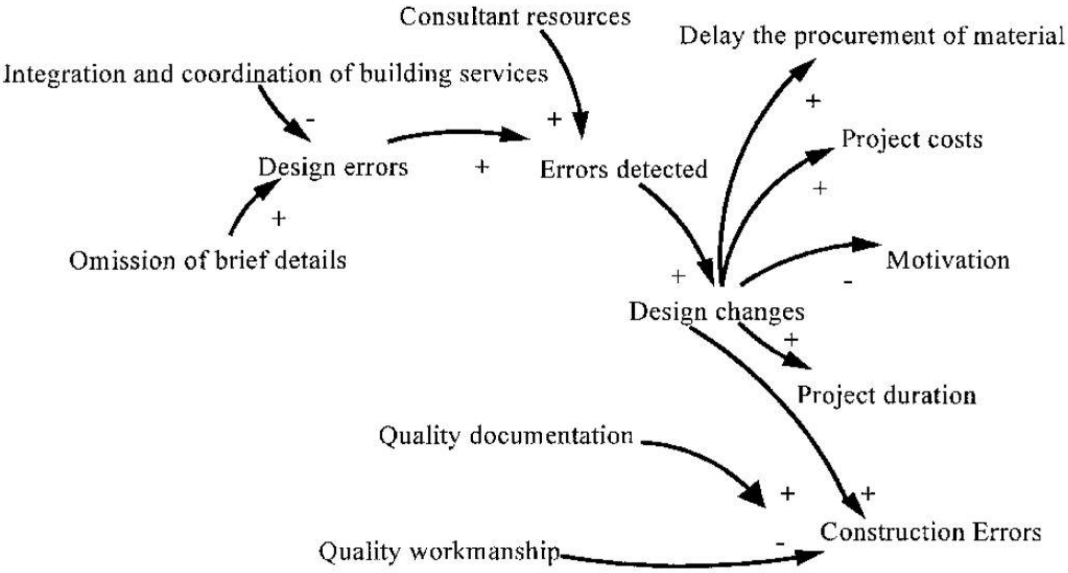


Figure 2.5. Technical and operational sub-system influence diagram
(Love et al., 1999b)

Figure 2.5 shows the technical and operational factors influencing rework. According to this figure, omission of brief details and integration and coordination of building services have influence on design errors positively and negatively in respect. Design errors and consultant resources act upon the errors detected positively which affects design changes. Design changes influence delay the procurement of material, project cost, project duration, construction errors directly and motivation inversely. Quality documentation directly, and quality workmanship inversely, act upon construction errors.

Quality management factors influencing rework and their relation are demonstrated in the Figure 2.6. It indicates that presence of quality management functions has direct effect on consultant/contractor relationship, contractor/subcontractor relationship, implementation of feedback mechanism, and it has inverse effect on design errors. Consultant/contractor relationship influence teamwork/joint problem solving which affect on-site problem solving both positively. Contractor/ subcontractor relationship act upon productivity and performance directly.

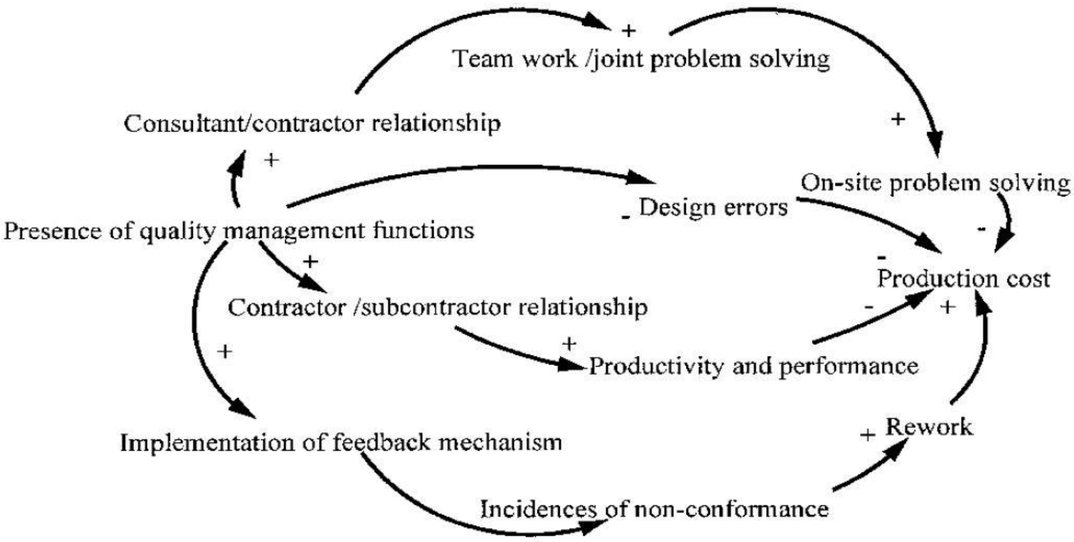


Figure 2.6. Quality management sub-system influence diagram
(Love et al., 1999b)

Implementation of feedback mechanism influence incidences of non-conformance negatively, which has the positive effect on rework. Finally, on-site problem solving, design errors, and productivity and performance influence production cost inversely, while rework act upon production cost directly.

The last sub-system is human resource and Figure 2.7 illustrates its factors influencing rework. Based on this figure, training and skill development act upon skill level and motivation directly. Skill level influence adequacy of personnel planning in a positive way which affect the project delay inversely. Skill level also has effect on defective workmanship inversely, and defective workmanship influence defects in construction directly. Motivation and defects in construction act upon incidences of rework inversely and directly, in respect.

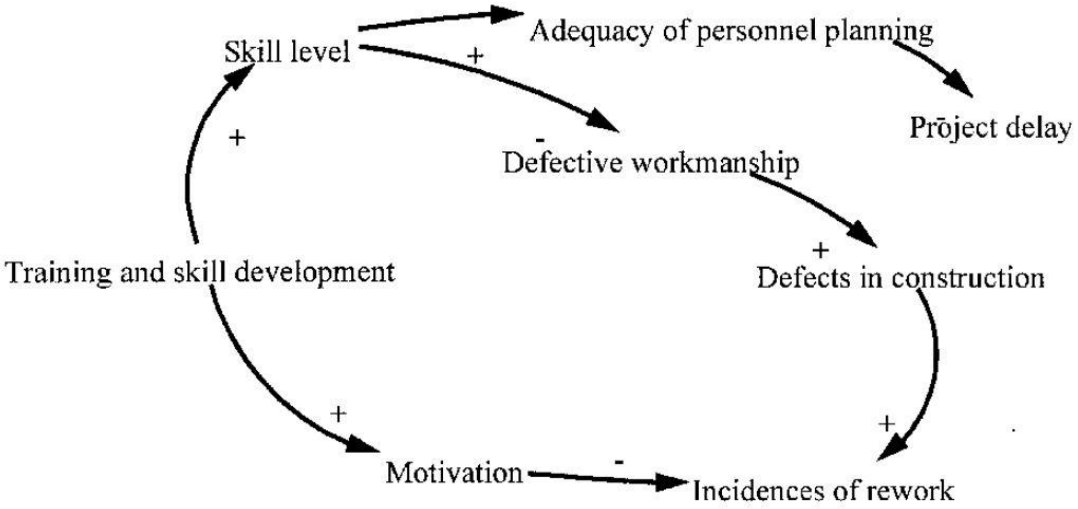


Figure 2.7. Human resource sub-system influence diagram
(Love et al., 1999b)

The utility of the above influence diagrams is describing the probable rework sequences if omissions or changes happen in some sections of the system. Figure 2.8 shows a causal model of the influencing rework factors in a system of project and it can be utilized to follow the influences or effects of rework elements on the project cost and duration as two important outputs of a project system.

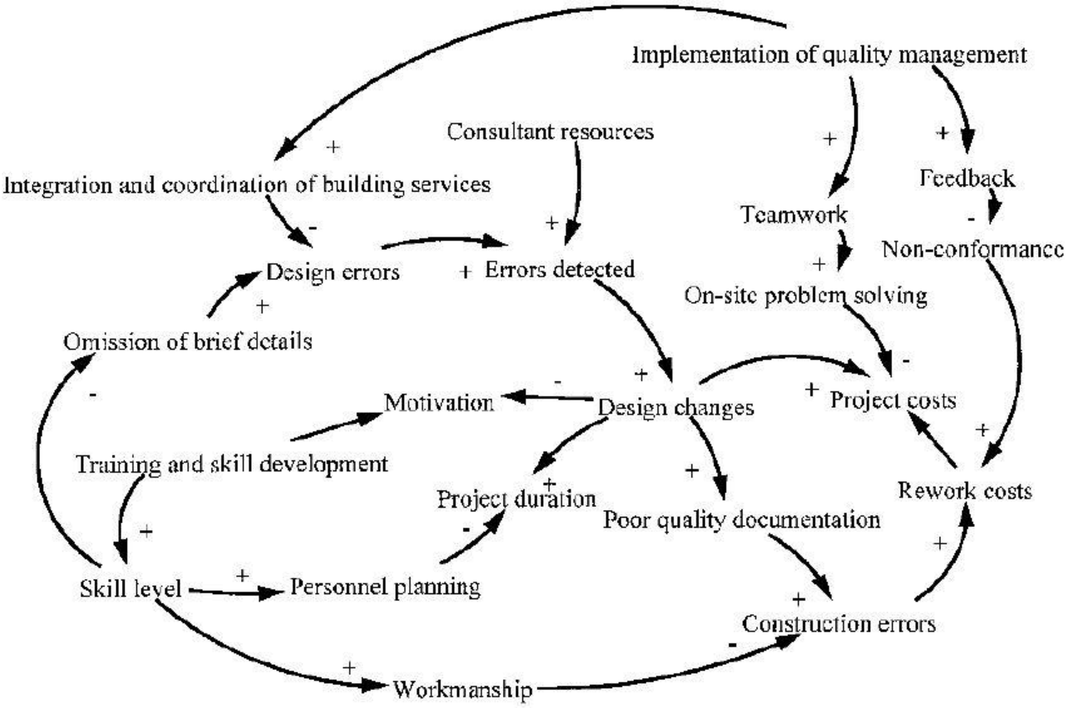


Figure 2.8. A causal model of rework in a project system
(Love et al., 1999b)

Based upon the above diagram, the effect of changes in the quality management implementation degree will influence project costs. Similarly, rework costs and project duration can be affected by training and skill development changes.

However, this diagram does not determine the influences on the system's causal variables by the major output factors. For instance, the influences an increasing in costs of project has on quality or skill increment programs. So Love et al. (1999b) created a rework's conceptual model based on causal modeling concepts (Figure 2.9). It illustrates the main factors that influence the project costs assuming that if there is an increase in project costs, it will negatively affect the project margins and the budget of quality and training to replace the extra costs of project. However, this budget reduction finally could increase the rework costs and project duration results in a cruel circle which can be identified with positive feedback loop A. The feedback loop B recommends that as project costs has positive effect on the strain on quality programs of organization, therefore the concentration on quality might be diverted. Feedback loop C shows direct relation between being quality focus and elimination of design errors and many others changes may be experienced. Similarly, an information link from costs of project to training and development of skill has made another main positive loop (D) which indicated that skill level will affect the workmanship quality, which consecutively can have a negative or positive influence on rework cost and project costs.

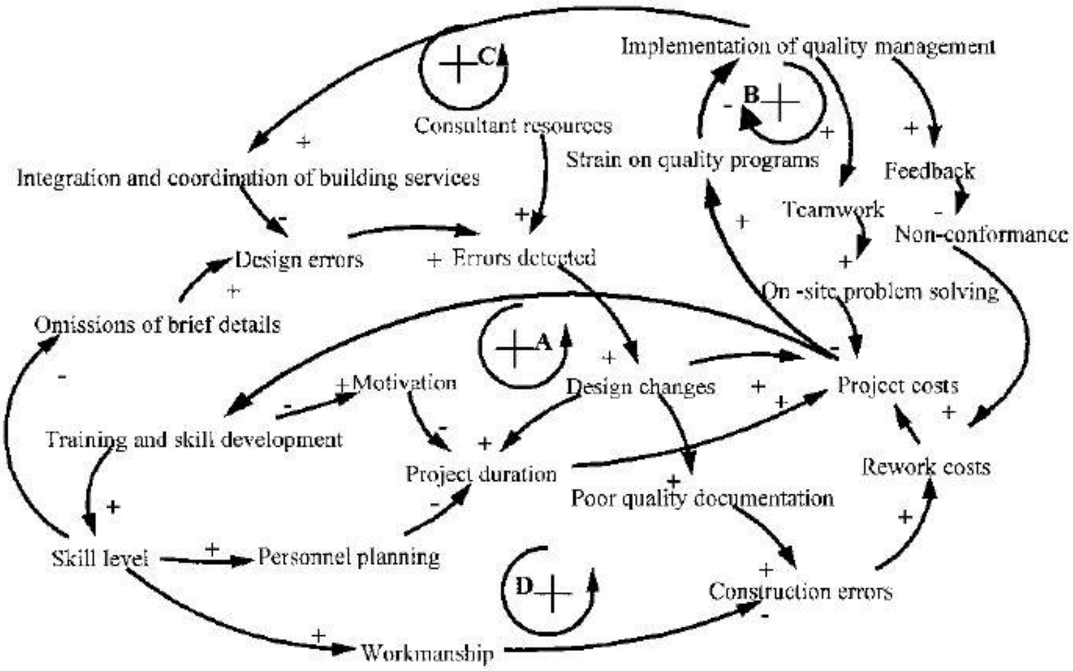


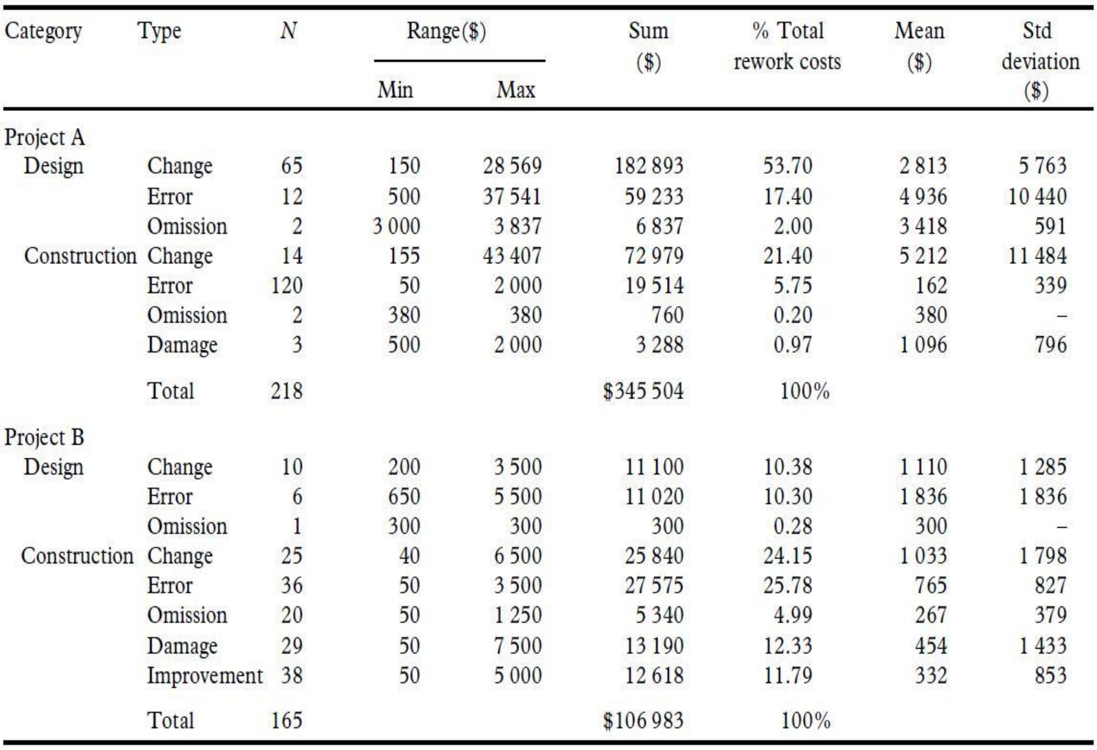
Figure 2.9. A conceptual model of rework based on causal modeling concepts (Love et al., 1999b)

The National Economic Development Office (NEDO) conducted a survey in 1987 which intended to identify ways of improving quality control in construction projects. It was demonstrated that the major of factors (90%) identified that influenced quality were referred to design (e.g. unclear and missing documentation, lack of design coordination) and poor or untrained workmanship (such as lack of knowledge and care). Another work done by NEDO (1998) revealed that half of defects in housing could be attributed to design (unclear and missing information), 30% to construction (poor workmanship), and the rest 20% to defective materials.

Hammarlund and Josephson (1991) proposed that a major cost of failures in building projects are attribute to the weak site management. They also found the main reasons of quality failures according to their priority are: defective or poor workmanship, flaws in products, substandard work breakdown, incorrect construction planning, inconveniences in planning of personnel, delays, changes, failure in scheduling, and failures in coordination.

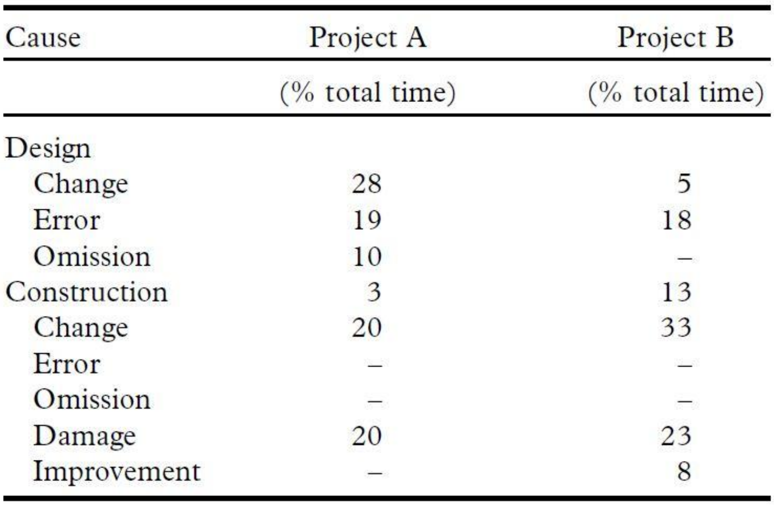
Love and Li (2000) studied on two different construction projects. Project A was residential project consisted of two 6-storey residential apartment blocks and project B was industrial warehouse comprised of 2 storeys. The rework costs, causes, and their signification of these two projects are provided in the Table 2.1. Table 2.2 gives the nonproductive time reasons of both projects. Nonproductive time is comprised of work inactivity and ineffective work. The former includes waiting time, idle time, travelling, and the latter includes rectifying mistakes and errors, working slowly and inventing work (Serpell et al., 1997). Total nonproductive time in projects A and B were 69 and 39 days, respectively.

Table 2.1. Rework costs, causes and their signification
(Love & Li, 2000)



Category	Type	N	Range($)		Sum ($)	% Total rework costs	Mean ($)	Std deviation ($)
			Min	Max				
Project A								
Design	Change	65	150	28 569	182 893	53.70	2 813	5 763
	Error	12	500	37 541	59 233	17.40	4 936	10 440
	Omission	2	3 000	3 837	6 837	2.00	3 418	591
Construction	Change	14	155	43 407	72 979	21.40	5 212	11 484
	Error	120	50	2 000	19 514	5.75	162	339
	Omission	2	380	380	760	0.20	380	–
	Damage	3	500	2 000	3 288	0.97	1 096	796
	Total	218			$345 504	100%		
Project B								
Design	Change	10	200	3 500	11 100	10.38	1 110	1 285
	Error	6	650	5 500	11 020	10.30	1 836	1 836
	Omission	1	300	300	300	0.28	300	–
Construction	Change	25	40	6 500	25 840	24.15	1 033	1 798
	Error	36	50	3 500	27 575	25.78	765	827
	Omission	20	50	1 250	5 340	4.99	267	379
	Damage	29	50	7 500	13 190	12.33	454	1 433
	Improvement	38	50	5 000	12 618	11.79	332	853
	Total	165			$106 983	100%		

Table 2.2. Causes of nonproductive time (Love & Li, 2000)



Cause	Project A	Project B
	(% total time)	(% total time)
Design		
Change	28	5
Error	19	18
Omission	10	–
Construction	3	13
Change	20	33
Error	–	–
Omission	–	–
Damage	20	23
Improvement	–	8

Result of seven case studies in Sweden (Josephson et al., 2002), which is shown in the Figure 2.10, illustrates the rework causes by their categories and their influences in rework costs. Based upon their study, the factors influencing rework costs in order of precedence are: design, production management, workmanship, material, client, and machines.

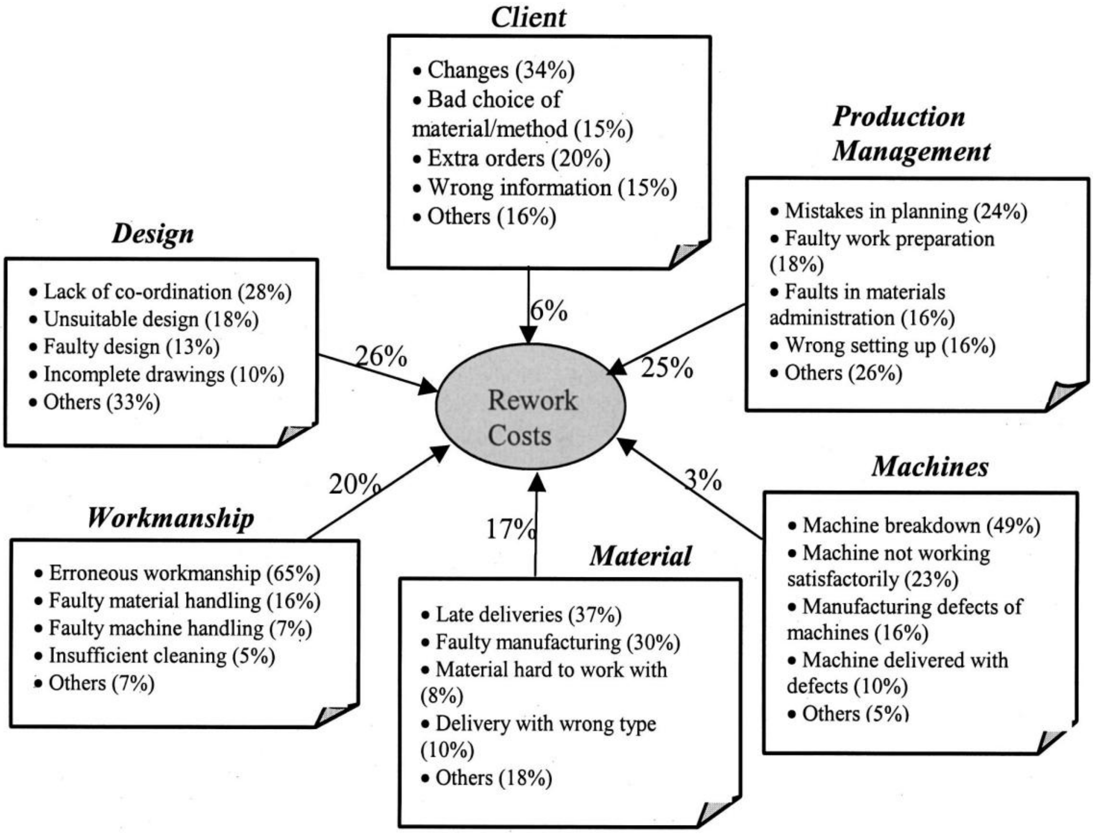


Figure 2.10. Factors contribute to rework and their influences in rework costs (Josephson et al., 2002)

Love and Edwards (2004) believe that the root causes of rework can be categorized into different groups such as:

- *Client related factors:* including lack of experience and knowledge of design and construction process, lack of client involvement in the project, lack of funding allocated for site investigations, inadequate briefing, inadequacies in contract and documentation, and poor communication with design consultants.
- *Design-related factors:* including ineffective use of quality management practices, poor coordination between different design team members, ineffective use of information technologies, lack of manpower to complete the required tasks, poor planning of workload, time boxing/ fixed time for a task, staff turnover/ re-allocation to other projects, insufficient time to prepare

contract documentations, incomplete design at the time of tender, and inadequate client brief to prepare detailed contract documentation.

- *Subcontractor related factors:* such as defects, damages, poor workmanship, use of poor quality materials, inadequate managerial skills, and specific problems associated with multi-layered subcontracting.
- *Other factors:* such as constructability associated concerns, poor site conditions, and environmental parameters. E.g. setting out errors, changes in construction methods to improve constructability, failure to provide protection to construction works, omissions of some activity or task.

Love et al. (1997) classifies causes of rework as it is shown in the Figure 2.11.

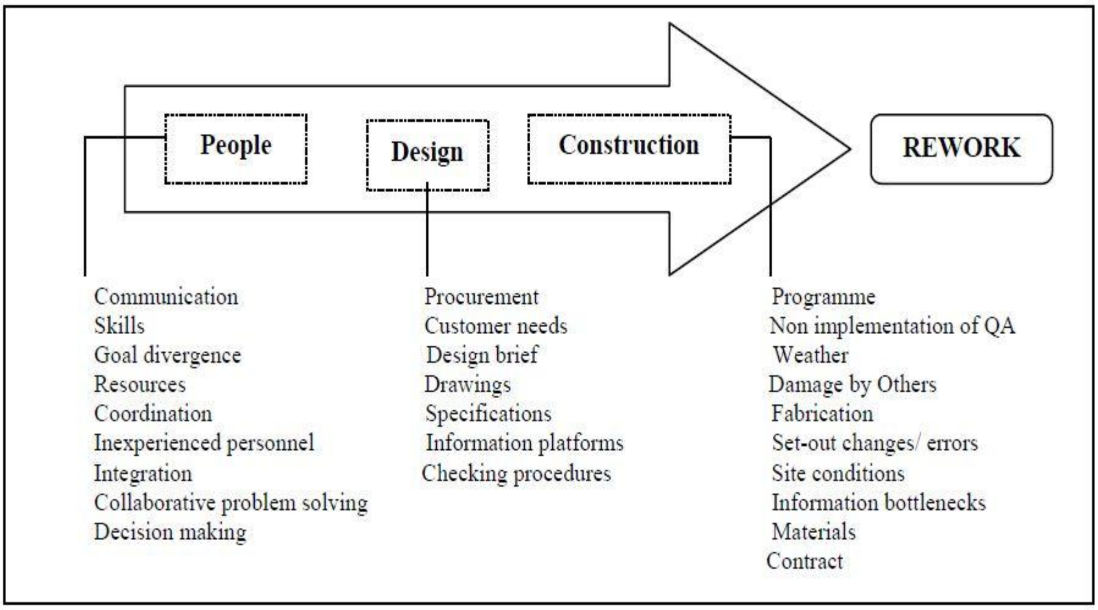


Figure 2.11. The classification of rework causes (Love et al., 1997)

Oyewobi and Ogunsemi (2010) categorized rework causes into three types of rework factors (technical factors, quality factors, and human resource factors) and find out the severity index of variables. Technical factors variables result in rework and their severity index are shown in the Table 2.3. It indicates the first three most severe cause of rework are: sub-standard product and services, defect, and ineffective coordination and integration of components.

Table 2.3. Variables of technical factors leading to rework and their severity index (Oyewobi and Ogunsemi, 2010)

Rework Causes	**Severity Index %**	**Rank**
Sub-standard services and product	51	1
Defect	50	2
Ineffective integration and coordination of components	49	3
Safety considerations	48	4
Change in scope and plan by client	47	5
Checking procedure	47	5
Lack of understanding and correct recitation of client’s requirement	47	5
Quality failure	45	8
Conflicting information	44	9
Inadequate resources	43	10
Complex details	41	11
Omitted site condition	41	11
Design errors	40	13
Design omissions	38	14

Table 2.4 gives the rework causes related to quality factors with their severity index. According to this table, late user involvement and lack of support to site management are the most severe causes. Lack of trust and commitment by participants is ranked after.

Table 2.4. Variables of quality factors leading to rework and their severity index (Oyewobi and Ogunsemi, 2010)

Rework Causes	**Severity Index %**	**Rank**
Late user involvement	60	1
Lack of support to site management	60	1
Lack of commitment and trust by participants	58	3
Poor teamwork	57	4
Cost pressure	55	5
Inadequate construction planning	54	6
Lack of quality management system	54	6
Poor information flow	54	6
Conflicting of opinions between participants	51	9
Contractor selection method	51	9
Poor management practice	49	11
Untimely delivering	49	11
Poor communication	47	13
Poor contractual relationship	47	13

Human resource factors and causes of rework are provided in the Table 2.5. In this category of rework factors, disturbance in personnel planning is the most severe item. Carelessness ranks as second most severe variable and lack of skill development and inexperienced personnel rank third.

Table 2.5. Human resource factors leading to rework and their severity index (Oyewobi and Ogunsemi, 2010)

Rework Causes	**Severity Index %**	**Rank**
Disturbance in planning of personnel	64	1
Carelessness	60	2
Inexperienced personnel	59	3
Lack of skill development	59	3
Inadequate funding	58	5
Uncertainty (weather, soil, etc)	56	6
Ignorance and lack of knowledge	55	7
Defective workmanship	52	8
Alteration	51	9
Delays	51	9
Lack of training	49	11
Staff turnover	47	12

Farrington (1987) classifies rework into three categories:

- *Change:* a directed action modifying the currently established requirements.
- *Error:* any activity or item in a system that is accomplished incorrectly resulting in a deviation.
- *Omission:* missing in any part of a system including design, construction, and fabrication resulting in a deviation.

Love et al. (2002) determine internal and external uncertainties that may not all lead to rework but in circumstances they can result in downtime and rework. Internal uncertainties might be

- Project-related: location conditions, uncertain duration for activities, uncertainties in the contract, uncertain costs, resource availability and limitations, and uncertain technical complexities.
- Organization-related: different contributors and other resources, different project stages require different skills. Project participants vary through the construction process.
- Finance-related: a company's financial policies can change. The changes in financial status can affect any party within the project team, or in the extreme even jeopardize the project's expected outcome.
- Interest-related: however all project participants may appear to desire realization of project goals, the interactive constraints and interests between disciplines often cause conflict. This can contribute to changes and affect the performance.
- Human-related: the effectiveness of human resource might change.

External uncertainties might be

- Economy-related: inflation, market competition, exchange rate, materials and finance, availability of labour.
- Technological: materials, techniques, facilities, labour, machines.
- Government-related: regulations, interest rates, taxes.
- Legal: changes in legislation, safety or planning laws.
- Social: changing social environment, resistances.

- Physical conditions: transportation, infrastructure, district development plans, degree of saturation.
- Institutional influences: education regulations, codes of conduct.
- Unexpected conditions: weather, natural disasters.

Recommended strategies for zero rework should embrace the following eight overlapping channels (Palaneeswaran, 2006):

1) Avoiding non-conformances, defects, errors, omissions, and other quality deviations (e.g. through quality management systems and appropriate supervisions.
2) Reducing changes and adversarial conflicts (e.g. through early involvements and enhanced stakeholder interactions, improved scope definitions including freezing from further changes, etc).
3) Enhancing systematization such as improved documentation, information and communication arrangements.
4) Selecting high value business partners: knowledgeable and understanding clients (including continuous monitoring of their satisfaction levels), best possible supply chain sources such as subcontractors and suppliers (including continuous monitoring of their performances as well as motivation levels).
5) Adopting suitable contractual safeguards and developing appropriate incentive/ disincentive mechanism.
6) Reinforcing relationships and enabling better supply chain integrations.
7) Utilizing relevant advanced construction technologies (e.g. standardization, prefabricated components, robotics and other automation).

8) Learning and training arrangements (e.g. through lessons learned frameworks, success and failure stories.

2.4 Impacts of Rework

According to the conceptual model of rework, which was provided in the Figure 2.1, rework has effect on the productivity and project performance. By the meaning of productivity, rework affects morale level, dilution of supervision, conflict, absenteeism, fatigue and communication. The impression of rework on project performance contains cost, time, quality, contractual claims, client satisfaction, design team satisfaction and contractor's satisfaction.

Since Burati et al (1992) defined rework as "quality deviations", it is obvious that rework and quality interact each other. Where quality control and management has not implemented adequately rework happens, and when it occurs the outcome quality will reduce. Unfortunately, the principles of total quality management (TQM) in the construction sector have not been implemented efficaciously. Consequently, rework has turn to an undeniable characteristic of the construction process. In addition of quality, the incidence of rework pushes the project out of the cost and time schedule and finally results to customer dissatisfaction.

It is essential to identify the costs and causes of construction rework in order to amend the performance of projects (Love and Li, 1999b). Measuring the level of rework can be utilized by management to evaluate how quality has been managed and to discover problems within the construction process. Davis et al. (1989), Low and Yeo (1998), and Abdul-Rahman (1993) have stressed the importance of measuring the costs of rework as a part of quality cost.

There are plenty of methods for calculation quality costs. As an example, costs can be classified as conformance costs and non-conformance costs. Conformance costs include indoctrination, training, verification, validation, testing, maintenance, inspection and audits. Conversely, non-conformance costs include items like waste of material, warranty repairs and rework (Love and Li, 2000). The other method of measuring costs of quality is suggested by Feigenbaum (1991). He classifies them into prevention, appraisal, and failure (Figure 2.12).

I. Costs of prevention include the total amounts invested or spent to prevent or leastwise importantly reduce defects or errors and with the purpose of eliminating their causes or resources before they occur.

II. Appraisal costs comprise the moneys spent on the catching of defects or errors by comparing different items with required level and standard specifications. Items such as: structural and architectural drawings, materials (such as bricks, door hardware, reinforcement, etc), work in progress and finished products.

III. There are two types of failure costs. The internal failure costs are the costs of detects or errors and fixing them while the product is still under control. On the opposite hand, external costs of failure are those incurred because of defects or errors identified after the product released or operated, and it is no more under control.

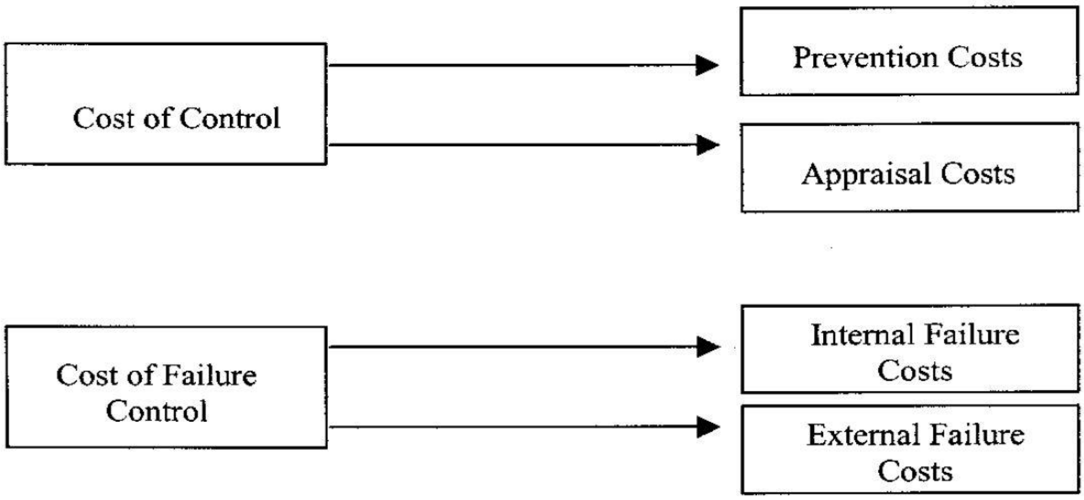


Figure 2.12. Quality costs (Feigenbaum, 1991)

According to the case study which was conducted by Love et al. (1998), in project A (residential apartment blocks) rework directly made the 3.15% cost of the contract value to be wasted and this cost for project B (industrial warehouse) was 2.40%. Davis et al. (1989) had undertaken similar research and detected poor quality costs as 12.4% of total contract value. Additionally, Hammarlund and Josephson (1996) figured out the range of costs of defects in construction projects were between 2.2% and 9% of total project cost.

However the direct costs of establishing quality system is quantifiable with some accuracy (such as salaries, audits, costs of documentation, etc), benefits of organizing this system are far more difficult to measure (Love and Li, 2000). Therefore, the importance of quality system does not get seriously attention and quality failures turn to unavoidable feature of construction projects which is undoubtedly result in cost and time overruns in projects.

Cnuddle (1991) specified the costs of failures in construction by measuring the non-conformance amount that happened on site. It was found that between ten percent and twenty percent of project cost is the cost of non-conformance. Moreover, total deviation costs were created during design stage was found to be 46% and deviation costs during construction was figured out as 22%. The Building Research Establishment, which is located in the United Kingdom, figured out that 50% of the origins of errors in buildings are in the design stage and 40% in the construction phase (BRE, 1981).

Burati et al. (1992) gathered quality aversions data from 9 industrial projects. In this research, they attempted to identify the degree and causes of quality problems in construction stage and design phase. According to their study, quality deviations can cost as high as 12.4% of total project cost. Actually, Burati et al. (1992) described that the quality deviations cost can be even more because some costs such as costs of schedule delays or litigation costs or any other intangible costs of poor quality are not included. Results of their study indicated that almost 80% of costs of deviations were related to design and 17% were construction related.

The BRE (1982) indicated that by utilizing a quality control system significant cost benefits can be achieved. The BRE demonstrated that 15% of total construction cost can be saved by eliminating rework.

Many systems have been produced to quantify the cost of construction quality. For instance, Ledbetter and Patterson (1989) produced a quality system to measure the quality costs by each activity. Four projects with the assumed rework cost of approximately 12.5% were utilized this system. After using the quality performance management system it was figured out that rework cost was around quarter of the project cost.

In similar, Abdul-Rahman (1995) expanded a matrix of quality costs for measuring the non-conformance cost of projects. His research outcomes revealed that the total non-conformance cost was 5% of tender value.

In the study of quality failures done by Hammarlund et al. (1990a, b), an observer used to record failures of quality within the construction of a community service building which took two years to complete. A total number of 1,460 quality failures were registered on site, of which 80% were corrected satisfactorily and 8% not corrected at all. Over a three week period another 21sites were inquired and the results indicated that 79% of failure costs came from 20% of the registered quality failures. The correcting cost of failures demonstrated to be 6% of production cost and an estimation time of 11% of the total working hours were taken to remediate these errors. It was also showed the positive effect of a quality observer presence on the quality of the project.

From 1990 to 1996, Josephson and Hammarlund conducted many studies to determine the defects causes and their associated costs on several building projects in Sweden (Josephson, 1990; Josephson 1994; Josephson and Hammarlund, 1996). Results of their studies showed that the cost of defects ranged between 2.3% and 9.4% of the contract value of each project. It was also indicated that 50% of the total costs of defects initiated on site and 32% initiated from the clients or inconsistencies of design.

A summary of previous researches have done on the nonconformance costs and their reasons is provided in the table 2.6.

Table 2.6. Nonconformance costs and reasons (Josephson et al., 2002)

Previous study	**Nonconformance costs**	**Reasons**
Cnuddle (1991)	10-20% of total project cost	46% created during design 22% for construction deviations
Building Research Establishment, BRE (1998)	-	50% originated from design And 40% from construction
National Economic Development Office, NEDO (1998)	-	50% attributable to design 30% due to construction 20% due to defective materials
Burati et al. (1992)	12.4% of total project cost	79% created during design 17% construction deviation costs
Hammarlund et al. (1990a, b)	11% of total project cost	79% of failure cost arose from 20% of quality failures
Hammarlund and Josephson (1991)	4% of total project cost	51% design related 26% related to poor installation of materials And 10% to material failure
Josephson (1990, 1994); Josephson and Hammarlund (1996)	2.3-9.4% of contract value of project	50% originated on site 32% originated from clients or design organizations

Results of seven case studies in Sweden by Josephson et al. (2002) indicated that the estimated correction costs amounted to SEK 7.25 million as of the 4.4% of the construction values for the period of observation. Furthermore, the results demonstrated 7.1% of the total work hours were spent on rework during the observation period.

Palaneeswaran (2006) believes that the direct impacts of rework on project management transactions include:

a) Additional time to do rework,
b) Additional costs to cover rework occurrences,
c) Additional materials for rework and handling the subsequent wastage, and
d) Additional labor force for rework and related extensions of supervision manpower.

The Construction Task Force in UK stated that the rework can be up to 30% of construction works (Egan, 1998) and the USA based Construction Industry Institute has calculated that as high as US$ 15 billion could be could be the annual loss due to rework for industrial construction projects (CII, 2001a).

Based on a description of Kumaraswamy and Chan (1998) and CII (2001b), rework is a substantial contributor to time wastage and schedule overruns. It will ultimately impact on quality, costs (e.g. indirect costs such as overheads) and resources as well (Love and Edwards, 2004).

Barber et al. (2000):

- This study examined the cost of quality failures in two highway construction projects in UK (obtained using Design-Build-Finance-Operate). The quality failure costs including the costs of delay were 16% of the construction cost for project one, and 23% for project two. If the costs of delay were excluded, the relevant quality failure costs were 3.6% and 6.6%.

Josephson et al. (2002):

- This Sweden based study identified the cost of defects from seven building projects which was ranged between 2.3% to 9.3% of contract value.
- The quality failure costs in another Sweden based study were found to be 6% of original contract value.

Fayek et al. (2003):

- In a Canada based study, the rework causes were categorized with their cost contribution percentage. These findings derived as cost contribution summary from the 108 field rework incidences:
    - Engineering and reviews: 61.65 %
    - Human resource capability: 20.49 %
    - Materials and equipment supply: 14.81 %
    - Construction planning and scheduling: 2.61 %
    - Leadership and communication: 0.45 %

Rhodes and Smallwood (2003):

- In a South Africa based study, 13% of the value of completed construction was found to be as the cost of rework.
- In the same article it was mentioned that the results of research on nine industrial projects which was conducted by Associated General Contractors

of America indicated that the average cost of rework was 12.4% of the project cost.

Love and Edwards (2004):

- Construction Industry Development Authority in Australia found that in the projects without having a formal quality management system, the average rework cost is 6.5% of the contract value. However, this number for the projects with a quality management system was found to be 0.72%.
- 161 projects were studied in another Australian based study (Love, 2002) and the average of direct and indirect costs of rework were found to be 6.4% and 5.6% of the original contract value respectively. This study also showed that the project contractual type may not have substantial influence on the rework costs.

Marosszeky (2006):

- In this Australia based study in New South Wales, the mean of rework costs were found as 5.5% of contract value including 2.75% as direct costs, 1.75% indirect costs for main contractors and 1% indirect costs for subcontractors.

Table 2.7 demonstrates several studies on the rework costs and their findings. It has been adapted from Love and Edwards (2004).

Table 2.7. Previous studies on rework costs and their findings
(Love & Edwards, 2004)

Author	**Year**	**Country**	**Rework Costs**	**Comments**
Cusack	1992	Australia	10% *	*= % of contract value †= % of project costs
Burroughs	1993	Australia	5% *	
CIDA	1995	Australia	6.5% *	
Lomas	1996	Australia	>1% *	
Love et al.	1999	Australia	2.4% & 3.15%*	
Love	2002	Australia	6.4% *	
CIDB	1989	Singapore	5-10% †	
Hammarlund et al.	1990	Sweden	6% †	
Josephson & Hammarlund	1990-1996	Sweden	2.3-9.4% *	
Josephson et al.	2002	Sweden	4.4% *	
Burati et al.	1992	USA	12.4% †	
Abdul-Rahman	1993	UK	2.5-5% *	

In another sampled private building project in Hong Kong which was observed by Ekambaram Palaneeswaran (2006), the direct costs of rework was found as 3.5% of original contract value and the related indirect costs was 1.7%. In this project, share of client, contractor and subcontractors in rework costs are as follow: a) client: 2% of direct costs and 1% of indirect costs, b) main contractor: 1% of direct costs and 0.5% of indirect costs, c) subcontractors: 0.5 of direct costs and 0.2% of indirect costs. The time overrun of this project was 2 months and the original period was 24 months.

The results of study on ten high-rise buildings by Alwi et al. (1999) demonstrated that the rework costs ranged from 2.01% to 3.21% of the total project costs. This study compared the rework costs of different projects with the amount of their training costs which is indicated in the figure 2.13. This figure shows that rework costs and training costs usually have a negative relationship. It seems the more money spent on training, the less the rework cost is (with the exception of one project). According to this study, contractors who have been conducted training programs regularly can reduce rework costs between 11% and 22%.

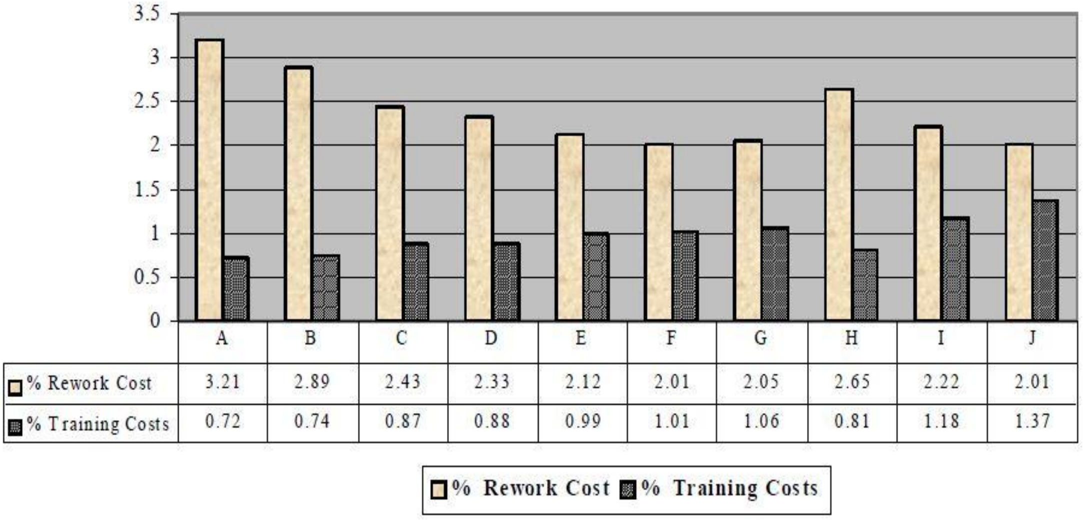


Figure 2.13. Rework costs and training costs
(Alwi et al., 1999)

Wasfy (2010) in the case study research on residential-commercial tower in Saudi Arabia categorized activities of construction and for each activity founds average frequency of rework, average percent of increase in cost, and average percent of delay. The results of this study are given in the following table (Table 2.8). In this table, rework frequencies are based on frequency scale of 0, 1, 2, 3, 4 representing never, rarely, sometimes, often, and always respectively.

Table 2.8. Frequency, cost, and delay of rework in construction activities (Wasfy, 2010)

Work category	**Average frequency of rework**	**Average percentage of increase in cost**	**Average percentage of delay**
Block works	3.00	30%	72%
Aluminum and glass works	2.33	7%	77%
Plaster works	2.00	17%	60%
Reinforced concrete works	1.67	7%	12%
Flooring and wall cladding works	1.67	22%	47%
Plumbing works	1.33	4%	29%
Electrical works	1.25	4%	21%
Air conditioning works	1.00	2%	12%
False ceiling works	0.67	2%	15%
Fire protection and fire fighting works	0.50	2%	10%
Wooden works	0.33	2%	10%
Elevator works	0.25	2%	15%

Referring to the above table, block works has the highest frequency of rework among construction activities and elevator works has the lowest frequency. Block works also has the first rank in the cost increasing because of reworks and has the second rank in the delay caused by rework after aluminum and glass works.

A similar research was done by Oyewobi et al. (2011) in Nigeria and they found the elemental cost of selected 25 institutional building projects, total variation cost and total rework cost of each of the elements which is represented in the following table.

Table 2.9. Elements of building and their contribution to reworks (Oyewobi et al., 2011)

	Additional			Variation		% of rework cost	% of rework cost	Cost
Elements	Initial cost	Works cost	Rework cost	Cost	Final cost	In variation cost	In final cost	Over run
Substructure	240.38	11.77	6.8	18.57	258.95	36.62	2.63	18.57
Frames and upper floors	172.38	10.64	7.36	18	190.38	40.89	3.87	18
Roof and covering	165.86	6.98	2.05	9.03	174.89	22.70	1.17	9.03
Wall	118.97	3.23	3.53	6.76	125.73	52.22	2.81	6.76
Doors and windows	75.56	8.67	4.03	12.7	88.26	31.73	4.57	12.7
Furniture and fittings	20.2	3.46	3.49	6.95	27.15	50.22	12.85	6.95
Mechanical installation	45.11	1.99	5.38	7.37	52.48	73.00	10.25	7.37
Electrical installation	69.21	1.46	0.85	2.31	71.52	36.80	1.19	2.31
Finishing	183.16	25.84	8.65	34.49	217.65	25.08	3.97	34.49
Painting	59.41	1.71	1.98	3.69	63.1	53.66	3.14	3.69
External works and	38.45	0.06	1.18	1.24	39.69	95.16	2.97	1.24

In the most of researches, direct and monetary impacts of rework have been focused. However, rework has additional indirect consequences and some of them are listed below (Love, 2002).

- End-user dissatisfaction
- Inter-organizational conflicts
- Fatigue
- Stress
- De-motivation
- Work inactivity
- Absenteeism
- Loss of future work
- Poor moral
- Reduced profit
- Damage to professional image

The mentioned factors can greatly influence a company's present or future well-being but they can hardly be assigned a monetary value.

2.5 Overview

Most of the mentioned researches in this chapter investigated the impacts of rework in construction generally, although some of them specified type of the project. This research focuses on rework impacts in constructing reinforced concrete structure as the most common type of structure in residential or residential-commercial buildings.

The results of this research confirm most of previous similar researches such as the research of Love et al. (1998) which found the direct cost of rework for residential apartment blocks as 3.15% of the construction cost, and the study of Alwi et al. (1999) which found the cost of rework in constructing 10 high-rise buildings ranged between 2.01% and 3.21% of the construction cost. However, they are the result of constructing the whole building but this research concentrates on constructing a reinforced concrete structure.

Wasfy (2010) determined the cost and time impact of rework in different construction activities and Oyewobi et al. (2011) did the similar research and found the rework cost in different construction elements. Similarly, this research finds out the cost and time impact of rework in different phases of constructing a reinforced concrete structure by investigating the rework items.

Chapter 3

METHODOLOGY

This chapter consists of two main sections, case study and questionnaire. Specifications of the projects and the method of collecting data are provided in this chapter.

3.1 Case Study

A construction project in Shiraz, Iran, was chosen as a case study project. In my opinion, Shiraz is the center of civil engineering in Iran and it has the most number of civil engineers in compare with the population in this country. It was awarded as the city with the best quality of construction in recent years in Iran, so the construction of this city represents the high quality construction among developing countries.

3.1.1 Project Specifications

The case study project was three blocks of 8-storeys residential buildings including 2 stroreys of parking and storage, and 6 residential storeys. Number of residential units of each floor was 5, so each block comprised of 30 residential units and the total number of units of the project was 90. Each residential floor consisted of 1 one-bedroom unit, 2 two-bedroom units, and 2 three-bedroom units with the area of 73, 100, and 127 square meters of each unit, respectively. The total construction area was 12000 square meters.

The volume of soil excavation of each block was 1700 cubic meters with the excavation area of around 500 square meters (28.5×17 meters) and the excavation height of 3.5 meters. Excavation was done mechanically by using loader for digging and truck to transfer the soil.

According to the results of soil test, constructing the pile under the foundation was needed. 6 circular reinforced concrete piles with a diameter of 1 meter and length of 8 meters with the same concrete specifications of foundation were constructed for each block.

10 centimeters of blinding concrete was placed on the soil. The total volume of cleaning concrete was 45 cubic meters with the cement ratio of 150 kilograms per cubic meter, which was transferred from batching plant to the site.

The type of foundation is mat foundation. 450 cubic meters of concrete were placed to construct the foundation of each block and this was done by discharging 65 truck mixers which transferred the concrete from batching plant of the Fars cement company. The thickness of foundation was 90 centimeters and it was constant for the whole foundation. The weight of reinforcement of each block’s foundation was 30 tons including two layers of steel bars at the top and bottom, and confirmatory bars. The required strength of foundation concrete was 250 kilogram per square centimeter for the 28 days cylinder sample. One concrete sample test was taken for every 50 cubic meters of concrete. Steel formwork was used and concrete was cured for 8 days by keeping it wet and under normal temperature.

The structure of building was reinforced concrete with shear walls, and two-way slabs for the roofs. Rectangular columns started with dimension of 50×50 centimeters on the basement and they reduced to 40×40 centimeters at the top. Dimension of beams was 40×40 centimeters and it was the same for all floors. The thickness of basement’s roof was 17 centimeters which was constructed by using two layers of steel bars (mesh), and the roof thickness of other floors were 15 centimeters. 2 ducts were passed through the slabs of top 6 storeys and 12 ducts from second floor to the top. 21 shear walls were constructed for each block of the project including: 5 shear walls with the thickness of 35 to 45 centimeters from the basement to the top, 9 shear walls with the thickness of 30 centimeters just in the underground floor, 5 shear walls with the same thickness just for the first two floors, and the rest 2 shear walls with the thickness of 20 centimeters from the second floor to the top. Each shear wall included two layers of steel bars.

Metal formwork was used for the structural concrete works. The concrete volume of the top 6 storeys was 140 cubic meters for each floor and the designed strength of concrete for structure including columns, beams, shear walls, and roofs was 300 kilograms per square centimeter for the 28 day cylinder sample. For every column and shear wall, one concrete test was performed.

3.1.2 Contractual and Supervision Conditions

Excavation phase of construction was done by the owners as they had excavation machines. The construction of structure including foundation, columns, beams, shear wall, and slabs was contracted by bidding. According to the tender’s condition, construction materials were provided by the owners and construction work was done by the contractor. The main contractor constructed the structure by hiring subcontractors for reinforcing, formwork and concrete work.

One full time site manager monitored the construction site on behalf of the owners to proctor the performance of the contractor and organize construction works in different phases. A construction company full-time supervised the building operations on behalf of the civil engineering organization of the city. According to the law, every construction site should be supervised by a registered construction company in order to get necessary permissions. In addition, the construction site was part-time inspected by the engineers of the municipality.

3.1.3 Data Collection

Data collection was done by observing the construction for duration of three months which was the quarter of construction period and also through a personal interview. Most of the interviews were taken from the supervisor of civil engineering organization as their data were most reliable.

The questions that were asked as follow:

1- How much money is wasted due to rework in percent of construction costs?
2- How long delay is happened due to rework in percent of construction period?
3- What are the percentage share of each factor such as contractor, consultant, and owner in the rework cost?
4- What are the reworks in excavation, reinforcing, formwork, and concrete work?

As there were more than one owner in this project, the owner means a group of owners. The full time site manager which has the responsibility on behalf of the owner acts as consultant in this case, and the meaning of contractor is the person or organization which was awarded the tender and was responsible for the construction.

3.2 Questionnaire

In addition to the case study, a questionnaire survey was undertaken among 22 construction projects.

3.2.1 Projects

22 Construction projects of reinforced concrete building were chosen for this survey. Most of the projects were residential apartments and few of them were residential-commercial buildings. Selected projects were medium to large in size, as they ranged between 5000 to 16000 square meters of construction area.

The projects were supervised by the construction organization which issues their permission and also they were inspected by the engineering of the municipality. This indicates that the minimum quality requirements were fulfilled in these projects. The minimum construction experience of the contractors was 5 years.

3.2.2 Data Collection

The questionnaire was designed to cover the aims and objectives of the research which are:

1- To find out the cost of reworks in reinforced concrete construction.
2- To determine the delay due to reworks.
3- To identify the share of contractor, owner, and consultant in cost of reworks.
4- To figure out the frequency of happening of rework items.
5- To categorize the rework items of in each phase of constructing reinforced concrete structure.

Based on the mentioned objectives, the questionnaire was designed (the sample of questionnaire is available in appendix) which was consisted of the following sections.

Section one included question about the cost of rework in percentage of construction cost, and time delay due to rework in percentage of construction duration. The data were used to draw the frequency chart and table of each rework cost, and time. The mean of rework costs and times were calculated as the representative cost and time impact of the rework in construction cost and duration.

Second section was designed to identify the share of contractor, owner, and consultant in rework. The respondents were asked to give the share of these factors in percent. The frequency chart and table of the share of each element in the costs of rework were prepared by using these data, and finally the graph of element's share in construction cost was drawn by getting the average of the collected data from 22 projects.

The third section of the questionnaire was shaped as a table, about the rework items. Based on the rework items found in case study project and by modifying them and adding some general reworks that happen in most of the construction projects with reinforced concrete structure, 17 rework items were provided in questionnaire. The respondents were asked to answer the following questions:

- Determine each of rework items happened during the construction. The results were utilized to find the relationship between rework items happening and investigate the correlation among the rework items of each phase of construction. For this purpose, factors analysis was used by utilizing the statistical package for the social sciences (SPSS) software version 20.

Factor analysis is a technique for identifying clusters or groups of variables. This technique has three main uses: 1) to understand the structure of a set of variables; 2) to measure an underlying variable; and 3) to reduce a data set to a more manageable size while retaining as much of the original information as possible. Factors are the underlying dimensions that could be measured as the same aspects of variables with the existence of clusters of large correlation coefficients between their subsets (Field, 2009).

The investigated rework items were related to the four phases of constructing a reinforced concrete structure; excavation, reinforcing, formwork, and concrete work.

The happening frequency of each rework item and their ranking were calculated.

- Determine the impact of rework items on the cost. For each rework item, the respondents were requested to answer the severity on rework cost. A five-point scale of 0 to 4 was adopted for evaluating the effect of each factor. These numerical values were assigned to the respondent's rating: 0= No severe, 1= Low severe, 2= Moderate, 3= Very severe, and 4= Extremely severe. Severity index is calculated then by using this formula:

$$S.I. = \frac{\sum_0^4 a_i n_i}{4N} \tag{3.1}$$

Where: a= constant expressing the weight assigned to each responses (ranges from 0 for no severe to 4 for extremely), n= frequency of each response, and N= total number of responses).

The importance index of item in rework cost is also calculated according to this equation:

$$IMP.I. = F.I \times S.I. \tag{3.2}$$

Frequency index was figured out from the previous part and the severity index was calculated from the above mentioned formula.

- The severity of impacts of rework items on time delay. For each rework item the severity of its effect on the time of rework was determined. The importance index in time of rework was also calculated. The scale and formulas were the same as the severity on rework cost which were given above.

Chapter 4

DATA ANALYSIS AND DISCUSSIONS

4.1 Introduction

Results of the study and their analysis are provided in this chapter with their explanations and discussions. This chapter is divided into four sections, the first section represents the cost of rework in the construction of reinforced concrete structure, the second section covers the time wasting of rework in the stated phase of construction, the third section presents the factors of rework (contractor, owner, consultant) and the influence of each one in the cost of rework, and the final section provides some rework items in different phases of construction, relations between the items of each phase, their frequency, and their effect on cost and time of rework.

4.2 Rework Cost

In this section, rework cost is given as a percentage of the construction cost of building a reinforced concrete structure. The average of rework costs of all projects are then calculated as the mean of rework cost.

The result of observations and data collection from case study project showed that the cost of rework was $33,225. This amount was gained by summing up the cost of rework items (the sample of rework items are given in the section 4.5) that happened during the construction. The construction activities that considered in this study were excavation, reinforcing, formwork and concrete work of constructing reinforced concrete structure. The total cost of construction was $1.8M. By dividing the cost of rework to the construction cost, it is found that the rework cost is around 1.85% of the construction cost during the observation period. It means that for the construction of reinforced concrete structure in the case study project, this amount of money is wasted due to rework.

The rework costs of 22 construction projects are shown in the Figure 4.1. This figure shows the frequency of each rework cost among the projects. The horizontal axis represents different rework costs in percentage of construction cost and the vertical axis indicates the frequency of each rework cost among the surveyed projects. The results are according to the data collected by a questionnaire survey from different constructing or constructed projects.

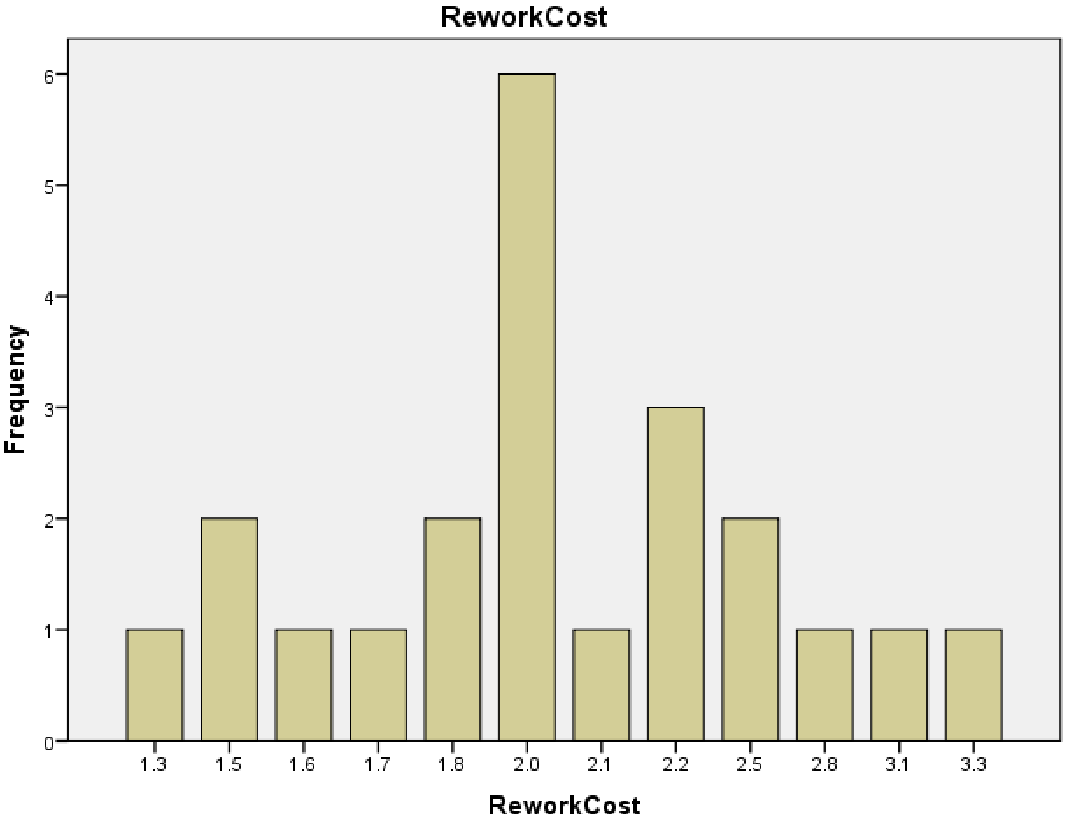


Figure 4.1. Rework costs and frequencies

All analysis and charts of this chapter are done and drawn by Statistical Package for Social Sciences or “SPSS” software version 20.

Table 4.1 indicates the rework costs and the frequency of each cost of rework in both number and percentage in 22 different projects. The most frequent cost of rework is 2% which happened in 6 projects with the frequency percent of 27.3%, the second one is 2.2% which was repeated in 3 projects with the frequency percent of 13.6%. 1.5, 1.8 and 2.5 percent are reported from 2 projects each one with 9.1% of frequency percent.

Table 4.1. Rework cost frequencies

Rework costs	Frequency	Percent	Valid Percent	Cumulative Percent
1.3	1	4.5	4.5	4.5
1.5	2	9.1	9.1	13.6
1.6	1	4.5	4.5	18.2
1.7	1	4.5	4.5	22.7
1.8	2	9.1	9.1	31.8
2.0	6	27.3	27.3	59.1
2.1	1	4.5	4.5	63.6
2.2	3	13.6	13.6	77.3
2.5	2	9.1	9.1	86.4
2.8	1	4.5	4.5	90.9
3.1	1	4.5	4.5	95.5
3.3	1	4.5	4.5	100.0
Total	22	100.0	100.0	

According to the Table 4.2, from 22 sample projects, the minimum cost of rework is 1.3% of construction of reinforced concrete structure and the maximum is 3.3%. The mean of rework costs is 2.095%.

Table 4.2. Rework cost descriptive statistics

Descriptive stat.	N	Minimum	Maximum	Mean	Std. Deviation
ReworkCost	22	1.3	3.3	2.095	.5019
Valid N (listwise)	22				

The rework cost of the case study project is 1.85% and the mean of rework cost gained from 22 projects is 2.095%. By dividing the first number to the second one and multiply it by hundred, it is found that there is an about 12% relative difference between these two and it is reasonable because the projects are different in size, conditions, supervisions and etc.

4.3 Rework Time

Rework times are provided as a percentage of the period of constructing reinforced concrete structure in this chapter. The time wastage of rework in the case study project comes first and the rework times of the 22 surveyed projects come after.

In the case study project, time delay due to rework was observed as 15 days and the duration of constructing the structure was 365 days so, the rework time in the case study project is 4.1% of the construction period. The mentioned time delay is the wasting time to make the rework items correct.

By a questionnaire survey, rework time of 22 construction projects were gathered and it is shown in the Figure 4.2. Different rework times in percent of construction duration are given in the horizontal axis and the frequency of each rework time among 22 surveyed projects are demonstrated in the vertical axis. It indicates the frequency of each rework time among the projects. In the figure, rework time are given as a percentage of construction period.

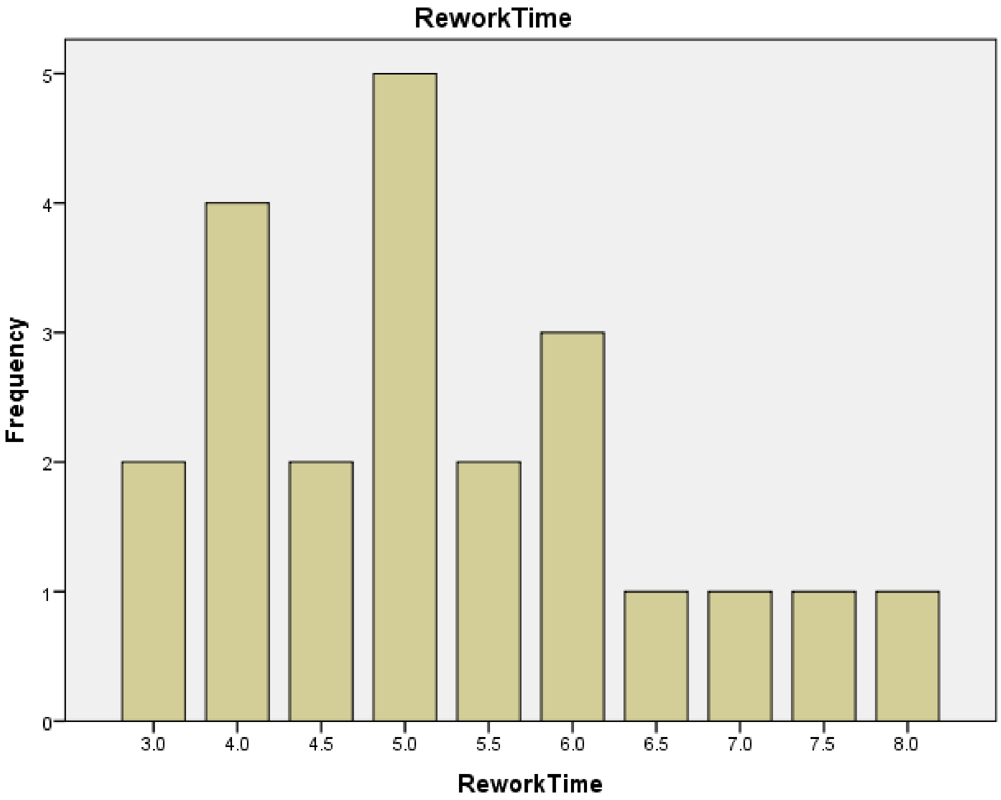


Figure 4.2. Rework times and frequencies

Table 4.3 indicates the rework times and the frequency of each number in both frequency number and percentage. It shows that from 22 projects, rework time of 5% is happened in 5 projects with frequency percent of 22.7%. The second most repeated rework time is 4% which is the same in 4 projects with frequency percent of 18.2%, and the third rank belongs to 6% rework time with 3 times or 13.6% repeating frequency. Rework times of 3%, 4.5%, and 5.5% are occurred 2 times each one.

Table 4.3. Rework time frequencies

Rework time	Frequency	Percent	Valid Percent	Cumulative Percent
3.0	2	9.1	9.1	9.1
4.0	4	18.2	18.2	27.3
4.5	2	9.1	9.1	36.4
5.0	5	22.7	22.7	59.1
5.5	2	9.1	9.1	68.2
6.0	3	13.6	13.6	81.8
6.5	1	4.5	4.5	86.4
7.0	1	4.5	4.5	90.9
7.5	1	4.5	4.5	95.5
8.0	1	4.5	4.5	100.0
Total	22	100.0	100.0	

Table 4.4 illustrates that according to the data collected from 22 construction projects, the minimum rework time of constructing a reinforced concrete structure is 3% of the construction period and the maximum number is 8%. The average of rework times is 5.182%. In compare to the rework time of case study project, which is 4.1%, the rework time of the surveyed projects is 1.082% more than case study project which shows about 21% relative difference.

Table 4.4. Rework time descriptive statistics

Descriptive stat.	N	Minimum	Maximum	Mean	Std. Deviation
ReworkTime	22	3.0	8.0	5.182	1.3233
Valid N (listwise)	22				

4.4 Rework Factors

Rework factors that investigated in this study are: contractor, owner, and consultant. The role of factors is shown as the percentage of rework cost happened because of each one’s mistakes.

4.4.1 Contractor

In the case study project, contractors were the most responsible factor in the costs of rework and it made 46% of rework costs. The results of survey are given in the Figure 4.3. In this figure, horizontal axis shows different percentages of the share of contractor in the rework cost and vertical axis indicates the frequency of each number among 22 surveyed projects.

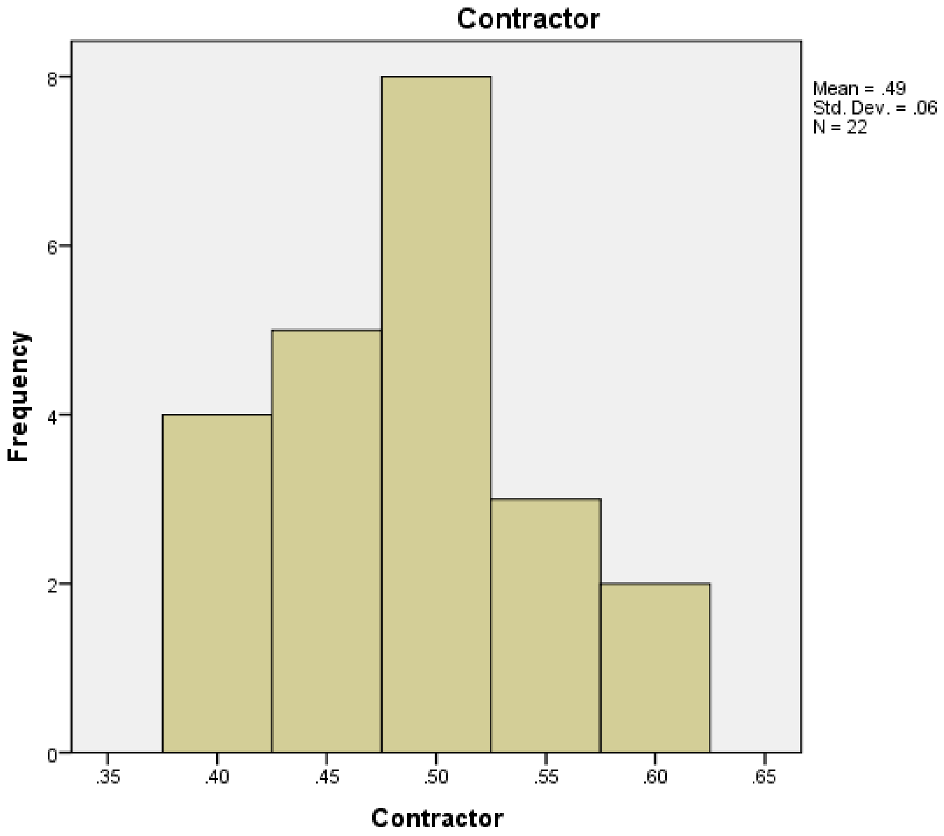


Figure 4.3. Contractor's share in rework cost

Table 4.5 indicates the percentage of contractor’s share in the cost of rework and the frequencies of repeating that percent among 22 projects. It shows that 50% share of contractor in rework cost is the most frequent, which happened in 8 projects.

Table 4.5. Frequencies of contractor's share in rework cost

Contractor's share	Frequency	Percent	Valid Percent	Cumulative Percent
.40	4	18.2	18.2	18.2
.45	5	22.7	22.7	40.9
.50	8	36.4	36.4	77.3
.55	3	13.6	13.6	90.9
.60	2	9.1	9.1	100.0
Total	22	100.0	100.0	

According to Table 4.6, the minimum influence of contractor in rework cost is 40% and the maximum is 60%. In average 48.64% of rework cost belongs to the contractor.

Table 4.6. Descriptive statistics of contractor's share in rework cost

Descriptive stat.	N	Minimum	Maximum	Mean	Std. Deviation
Contractor	22	.40	.60	.4864	.06012
Valid N (listwise)	22				

4.4.2 Owner

The share of owner in the cost of rework in the case study project was 37% of the rework cost, indicates that owner is the second most important factor in the rework cost after contractor.

According to the survey of 22 construction projects, the owner's shares in the rework cost are shown in the Figure 4.4. In this figure, horizontal axis represents various percentages of the share of owner in rework cost and the vertical axis determines the frequency.

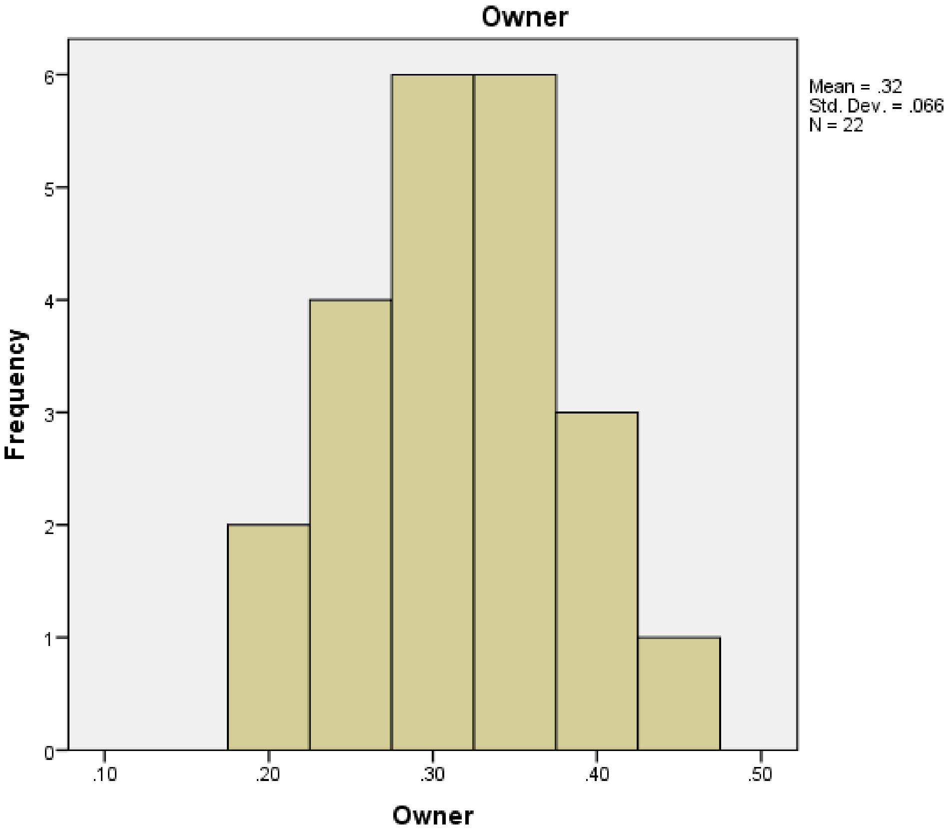


Figure 4.4. Owner's share in rework cost

The owner’s share percentages in the rework cost and their frequency gathered from surveyed projects are demonstrated in Table 4.7. Referring to this table, 30% and 35% share of owner in rework cost are the most frequent and each one is repeated in 6 projects.

Table 4.7. Frequencies of owner’s share in rework cost

Owner's share	Frequency	Percent	Valid Percent	Cumulative Percent
.20	2	9.1	9.1	9.1
.25	4	18.2	18.2	27.3
.30	6	27.3	27.3	54.5
.35	6	27.3	27.3	81.8
.40	3	13.6	13.6	95.5
.45	1	4.5	4.5	100.0
Total	22	100.0	100.0	

Table 4.8 illustrates that 20% is the minimum share of owner in rework cost, 45% is the maximum, and the mean is 31.59% among data collected from 22 projects.

Table 4.8. Descriptive statistics of owner’s share in rework cost

Descriptive stat.	N	Minimum	Maximum	Mean	Std. Deviation
Owner	22	.20	.45	.3159	.06616
Valid N (listwise)	22				

4.4.3 Consultant

The share of consultant in cost of rework in the case study project was observed as 17%. The results of survey from 22 constructions projects are given in Figure 4.5. Horizontal axis in this chart indicates different percentages of shares of consultant in rework cost and vertical axis shows the frequency among surveyed projects.

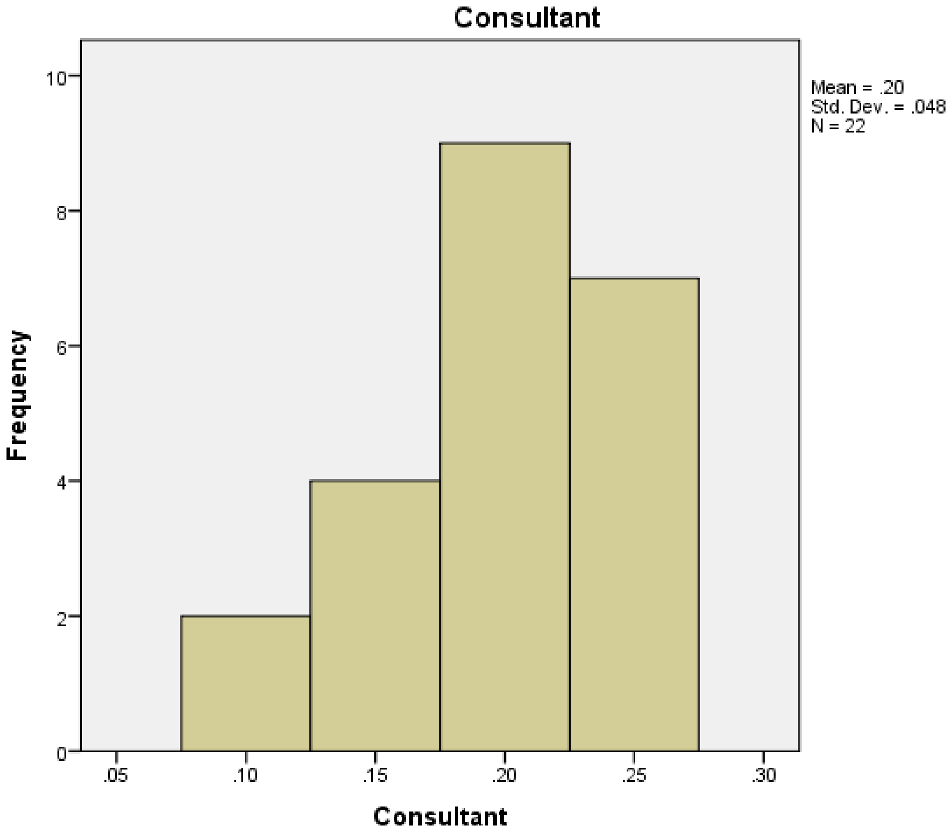


Figure 4.5. Consultant's share in rework cost

Table 4.9 demonstrates the consultant’s share in rework cost and frequency of repeating in surveyed projects. It indicates that in 9 projects out of 22 projects, the share of consultant in rework cost is 0.2 or 20%.

Table 4.9. Frequencies of consultant’s share in rework cost

Consultant's share	Frequency	Percent	Valid Percent	Cumulative Percent
.10	2	9.1	9.1	9.1
.15	4	18.2	18.2	27.3
.20	9	40.9	40.9	68.2
.25	7	31.8	31.8	100.0
Total	22	100.0	100.0	

According to the Table 4.10, the minimum share of consultant in rework cost is 10% and the maximum is 25%. The mean of data is 19.77%.

Table 4.10. Descriptive statistics of consultant’s share in rework cost

Descriptive stat.	N	Minimum	Maximum	Mean	Std. Deviation
Consultant	22	.10	.25	.1977	.04750
Valid N (listwise)	22				

Based on the mentioned data analysis, a chart of factor’s share in rework cost can be drawn. Share of three factors (contractor, owner, and consultant) in the cost of rework in the case study project is provided as a pie chart in Figure 4.6. It shows that 46% of the rework cost are caused by the contractors, 37% by the owner (or owners in this case), and 17% by the consultant.

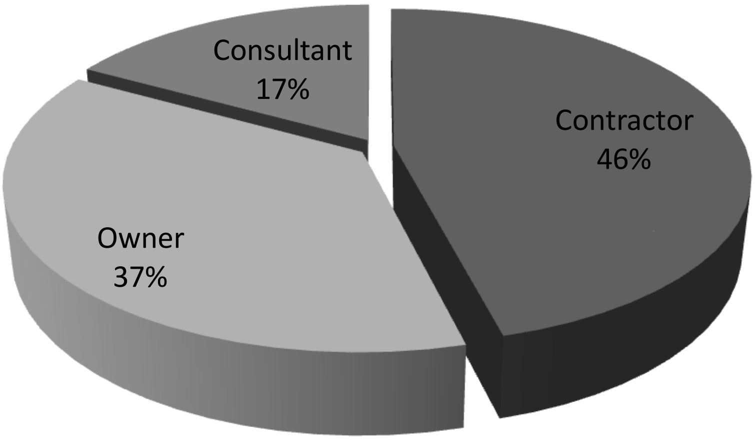


Figure 4.6. Factor’s share in rework cost in the case study project

Figure 4.7 shows the average of factor’s share in rework cost in 22 surveyed construction projects as a pie chart. According to this figure, share of contractors in rework cost is almost 49%, it is more than 31% for owners, and around 20% for consultants.

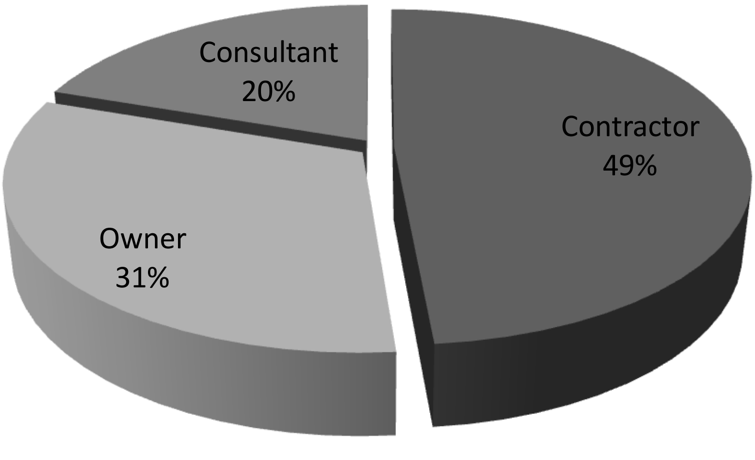


Figure 4.7. Factor’s share in rework cost in surveyed projects

4.5 Rework Items

The rework items observed in the case study project and typical items that occur in most of the construction of reinforced concrete structures are investigated in this research. These items are:

1- Over excavation.
2- Collapsing excavation walls.
3- Appearing cracks at the corners of concrete elements.
4- Displacement of formwork at the time of placing concrete.
5- Falling formwork materials from top storeys that causes damage to them.
6- Bad appearance of concrete surface caused by deformation of formworks.
7- Fabricating inaccurately dimensioned concrete elements.
8- Damaging formwork materials due to irregular shapes with non-standard sized modular panels.
9- Leaking concrete from joints of the formwork.
10- Changing the designed steel bar diameters due to unavailability.
11- Wasting the reinforcement bars by wrong workmanship.
12- Remaining reinforcement bars at the end of construction.
13- Lacking reinforcement bars.
14- Using inappropriate head for poker vibrators.
15- Forming cold joint due to mismanagement of concrete delivering to the site.
16- Allocating inappropriate concrete materials.
17- Demolishing or repairing some parts of concrete due to non-conformance to the specification.

4.5.1 Rework Items Frequency

The frequency of rework items among 22 construction projects, and their frequency ranking are provided in Table 4.11.

Table 4.11. Frequency of rework items

Items	**Frequency (out of 22)**	**Frequency percent**	**Rank**
Rework item 10	14	63.6	1
Rework item 14	13	59.1	2
Rework item 13	12	54.5	3
Rework item 16	12	54.5	3
Rework item 9	11	50	5
Rework item 15	11	50	5
Rework item 8	10	45.5	7
Rework item 12	10	45.5	7
Rework item 4	9	40.9	9
Rework item 6	7	31.8	10
Rework item 7	7	31.8	10
Rework item 3	6	27.3	12
Rework item 5	6	27.3	12
Rework item 11	6	27.3	12
Rework item 1	5	22.7	15
Rework item 2	4	18.2	16
Rework item 17	3	13.6	17

4.5.2 Categories of Rework Items

To categorize the rework items, the relations and correlations between each pair of items should be discovered. For this purpose, factor analysis is done on 17 rework items by utilizing IBM SPSS software version 20.

The principal component method of extraction is used for the analysis. The Kaiser-Meyer-Olkin (KMO) measure of adequacy and Bartlett's test of sphericity are run on the data, and the results are shown in the Table 4.12. The KMO statistic varies between 0 and 1 (Field, 2009). A value of zero indicates that the sum of partial correlations is large relative to the sum of correlations, indicating diffusion in the pattern of correlations which shows factor analysis is inappropriate. A value close to 1 indicates that patterns of correlations are relatively compact and so factor analysis should yield distinct and reliable factors. The KMO value should be at least 0.5 (Kaiser, 1974) and it is 0.636 in this research which is acceptable.

Bartlett's measure tests the null hypothesis that the original correlation matrix is an identity matrix and it should be significant (i.e. have a significance value less than 0.05) (Field, 2009). A significant test demonstrates that there are some relationships between the variables. For these data Bartlett's test was highly significant (<0.001), and therefore factor analysis was appropriate.

Table 4.12. KMO and Bartlett's test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.636
Bartlett's Test of Sphericity	Approx. Chi-Square	253.324
	df	136
	Significance value.	.000

The anti-image correlation matrix is provided in Table 4.13. This matrix contains measure of sampling adequacy for each variable along the diagonal and the negatives of the partial correlation on the off-diagonals. The diagonal elements should all be greater than 0.5 at a bare minimum if the sample is adequate for a given pair of variables.

Table 4.14 lists the eigenvalues associated with each linear component (factor) before extraction, after extraction, and after rotation. The varimax method of rotation is used in the analysis. Before extraction, 17 linear components had been identified within the data set (same number of factors and variables). The eigenvalues associated with each factor represent the variance by that particular linear component and table shows the eigenvalue in terms of the percentage of variance explained. All factors with eigenvalues greater than 1 are then extracted, which left four factors. The eigenvalues associated with these factors and the percentage of variance explained, are again displayed in the columns labeled Extraction Sums of Squared. In the final part of the table, the eigenvalues of the factors after rotation are displayed.

Table 4.13. Anti-image correlation matrix

		Item1	Item2	Item3	Item4	Item5	Item6	Item7	Item8	Item9	Item10	Item11	Item12	Item13	Item14	Item15	Item16	Item17
Anti-image Correlation	Item1	.534[a]	-.805	-.054	-.216	-.189	-.204	.087	.269	.151	.158	.216	.060	-.056	.197	.182	.145	-.088
	Item2	-.805	.605[a]	-.111	.156	.313	.116	.156	-.025	.022	-.384	-.059	.178	.204	.046	-.097	-.121	.269
	Item3	-.054	-.111	.581[a]	-.428	-.182	-.618	-.871	-.289	.526	.368	.069	-.554	.092	-.261	-.346	.089	.278
	Item4	-.216	.156	-.428	.666[a]	-.249	.511	.286	-.134	-.646	-.088	-.099	.036	.049	.011	-.102	-.162	-.274
	Item5	-.189	.313	-.182	-.249	.788[a]	.007	.158	.075	.074	-.258	-.057	.233	.127	-.118	.123	.117	.179
	Item6	-.204	.116	-.618	.511	.007	.694[a]	.267	-.319	-.502	-.119	-.390	.170	-.107	.093	-.027	-.164	-.233
	Item7	.087	.156	-.871	.286	.158	.267	.554[a]	.407	-.431	-.506	.082	.705	-.040	.368	.466	-.135	-.265
	Item8	.269	-.025	-.289	-.134	.075	-.319	.407	.794[a]	-.217	-.050	.299	.125	.114	-.074	.260	.342	.071
	Item9	.151	.022	.526	-.646	.074	-.502	-.431	-.217	.688[a]	.076	.129	-.037	-.009	.227	-.129	-.017	.429
	Item10	.158	-.384	.368	-.088	-.258	-.119	-.506	-.050	.076	.531[a]	-.133	-.600	-.522	-.308	-.375	.298	.141
	Item11	.216	-.059	.069	-.099	-.057	-.390	.082	.299	.129	-.133	.732[a]	-.193	.227	.054	.245	.030	.021
	Item12	.060	.178	-.554	.036	.233	.170	.705	.125	-.037	-.600	-.193	.557[a]	-.158	.538	.481	-.316	-.238
	Item13	-.056	.204	.092	.049	.127	-.107	-.040	.114	-.009	-.522	.227	-.158	.792[a]	-.101	-.043	.141	.064
	Item14	.197	.046	-.261	.011	-.118	.093	.368	-.074	.227	-.308	.054	.538	-.101	.623[a]	.105	-.526	-.088
	Item15	.182	-.097	-.346	-.102	.123	-.027	.466	.260	-.129	-.375	.245	.481	-.043	.105	.569[a]	-.403	-.366
	Item16	.145	-.121	.089	-.162	.117	-.164	-.135	.342	-.017	.298	.030	-.316	.141	-.526	-.403	.656[a]	.122
	Item17	-.088	.269	.278	-.274	.179	-.233	-.265	.071	.429	.141	.021	-.238	.064	-.088	-.366	.122	.570[a]

a. Measures of Sampling Adequacy(MSA)

Table 4.14. Total variance explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.629	33.109	33.109	5.629	33.109	33.109	4.695	27.618	27.618
2	3.668	21.575	54.684	3.668	21.575	54.684	3.048	17.928	45.545
3	2.287	13.453	68.137	2.287	13.453	68.137	2.889	16.996	62.541
4	1.171	6.887	75.024	1.171	6.887	75.024	2.122	12.483	75.024
5	.854	5.022	80.046						
6	.776	4.567	84.613						
7	.621	3.651	88.264						
8	.589	3.463	91.726						
9	.407	2.395	94.121						
10	.266	1.566	95.687						
11	.218	1.282	96.969						
12	.166	.978	97.947						
13	.140	.826	98.774						
14	.085	.501	99.274						
15	.060	.353	99.627						
16	.050	.292	99.919						
17	.014	.081	100.000						

Extraction Method: Principal Component Analysis.

Scree plot is given in the Figure 4.8. This graph shows each eigenvalue (Y-axis) against the factor with which it is associated (X-axis). By graphing the eigenvalues, the relative importance of each factor becomes apparent. This figure indicates that there is a significant drop in the curve from the first component to the fourth but thereafter, it begins to tail off and continues with a smooth slope. That explains why four factors are extracted in this analysis.

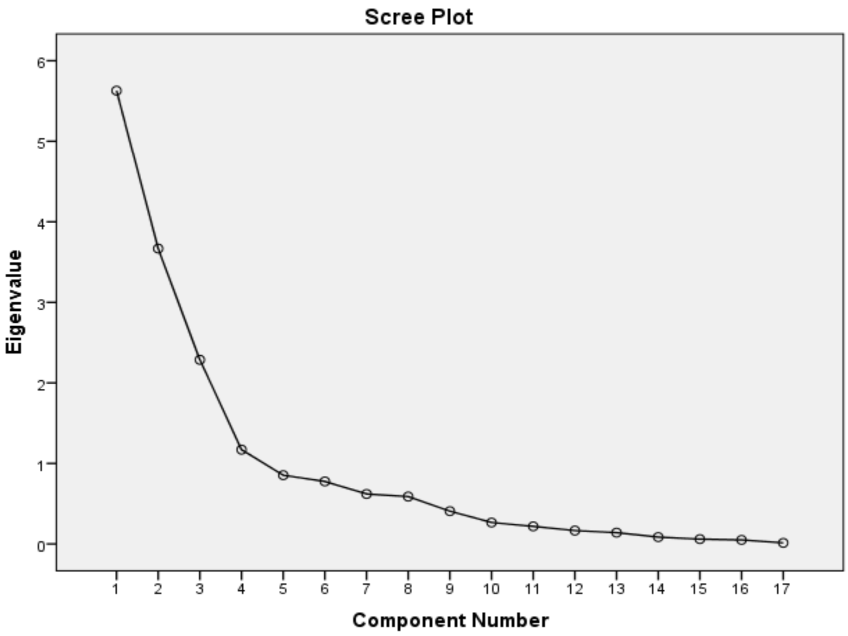


Figure 4.8. Scree plot

Table 4.15 shows the rotated component matrix which is a matrix of the factor loadings for each variable onto each factor. As it was mentioned, varimax method is used for the factor rotation, and loadings less than 0.4 are eliminated, as it is proposed by Field (2009). This table illustrates that each rework item is more correlated with which one of four factors or components.

Table 4.15. Rotated component matrix

	Component			
	1	2	3	4
Item1				.918
Item2				.913
Item3	.943			
Item4	.607			
Item5	.624			
Item6	.900			
Item7	.893			
Item8	.699			
Item9	.739			
Item10		.920		
Item11		.608		
Item12		.779		
Item13		.863		
Item14			.803	
Item15			.886	
Item16			.842	
Item17			.568	

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

By investigating the rework items, it is found that each component represents one phase of constructing reinforced concrete structure. Rework items 1 & 2 (component 4) are related to the excavation works. Rework items 3 to 9 (component 1) are all related to the formwork. Rework items 10 to 13 (component 2) are related to the reinforcing, and the rest 4 items (component 3) are related to the concrete work. Summary of the factor analysis on rework items is provided in the Table 4.16

Table 4.16. Summary of exploratory factor analysis results

Item	**Rotation factor loadings**			
	Formwork	**Reinforcing**	**Concrete work**	**Excavation**
Over excavation	-.116	-.128	-.168	**.918**
Collapsing excavation walls	-.300	-.014	-.053	**.913**
Appearing cracks at the corners of concrete elements	**.943**	-.074	-.007	.012
Displacement of formwork at the time of placing concrete	**.607**	-.337	.202	-.287
Falling formwork materials from top storeys that causes damage them.	**.624**	-.202	.017	-.081
Bad appearance of concrete surface caused by deformation of formwork	**.900**	.021	-.146	-.074
Fabricating inaccurately dimensioned concrete elements	**.893**	-.051	-.098	-.011
Damaging formwork materials due to irregular shapes with non-standard sized modular panels	**.699**	-.258	-.314	-.329
Leaking concrete from joints of the formwork	**.739**	-.221	-.255	-.336
Changing the designed steel bar diameters due to unavailability	-.033	**.920**	-.063	.108
Wasting the reinforcement bars by wrong workmanship	-.170	**.608**	-.313	-.139

Table 4.16 (continued)

Item	**Rotation factor loadings**			
	Formwork	**Reinforcing**	**Concrete work**	**Excavation**
Remaining reinforcement bars at the end of construction	-.358	**.779**	-.241	-.104
Lacking reinforcement bars	-.130	**.863**	-.050	-.060
Using inappropriate head for poker vibrators	-.131	-.248	**.803**	-.106
Forming cold joint due to mismanagement of concrete delivering to the site	.042	-.168	**.886**	.041
Allocating inappropriate concrete materials	-.094	-.233	**.842**	-.054
Demolishing or repairing some parts of concrete due to non-conformance to the specification	-.312	.199	**.568**	-.263
Eigenvalues	5.629	3.668	2.287	1.171
% of variance	33.11	21.58	13.45	6.89

4.5.3 Cost Effect of Rework Items

Effect of each rework item in cost can be demonstrated by importance index (IMP.I.) of that item in cost. Importance index is the result of multiplying frequency index (F.I.) and severity index (S.I.). The method of calculating these indexes was explained in the previous chapter.

In the excavation phase of construction, over excavation affects the cost more than collapsing excavation walls (Table 4.17).

Table 4.17. Cost effect of excavation rework items

Item	F.I.	S.I.	IMP.I.	Rank
Over excavation	0.500	0.386	0.178	1
Collapsing excavation walls	0.182	0.739	0.134	2

Table 4.18 shows the cost effect of rework items in phase of reinforcing. Changing the designed steel bar diameters due to unavailability has the most influence on cost.

Table 4.18. Cost effect of reinforcing rework items

Item	F.I.	S.I.	IMP.I.	Rank
Changing the designed steel bar diameters due to unavailability	0.636	0.511	0.325	1
Remaining reinforcement bars at the end of construction	0.455	0.466	0.212	2
Lacking reinforcement bars	0.545	0.307	0.167	3
Wasting the reinforcement bars by wrong workmanship	0.273	0.488	0.133	4

The cost influence of rework items in formwork phase of constructing a reinforced concrete structure is given in Table 4.19.

Table 4.19. Cost effect of formwork rework items

Item	F.I.	S.I.	IMP.I.	Rank
Leaking concrete from joints of the formwork	0.500	0.329	0.165	1
Damaging formwork materials due to irregular shapes with non-standard sized modular panels	0.455	0.318	0.145	2
Bad appearance of concrete surface caused by deformation of formwork	0.318	0.295	0.094	3
Falling formwork materials from top storeys that causes damage to them	0.273	0.341	0.093	4
Fabricating inaccurately dimensioned concrete elements	0.318	0.261	0.083	5
Displacement of formwork at the time of placing concrete	0.409	0.193	0.079	6
Appearing cracks at the corners of concrete elements	0.273	0.215	0.059	7

Finally, Table 4.20 gives the cost influence of rework items in phase of concrete work.

Table 4.20. Cost effect of concrete-work rework items

Item	F.I.	S.I.	IMP.I.	Rank
Allocating inappropriate concrete materials	0.545	0.614	0.335	1
Forming cold joint due to mismanagement of concrete delivering to the site	0.500	0.443	0.221	2
Using inappropriate head for poker vibrators	0.591	0.239	0.141	3
Demolishing or repairing some parts of concrete due to non-conformance to the specification	0.136	0.705	0.096	4

Table 4.21 presents the influence of rework items on cost in constructing a reinforced concrete structure.

Table 4.21. Cost effect of rework items in constructing a reinforced concrete structure

Item	**Frequency Index (FI)**	**Severity Index (SI)**	**Importance index FI × SI**	**Rank**
Allocating inappropriate concrete materials	0.545	0.614	0.335	1
Changing the designed steel bar diameters due to unavailability	0.636	0.511	0.325	2
Forming cold joint due to mismanagement of concrete delivering to the site	0.500	0.443	0.221	3
Remaining reinforcement bars at the end of construction	0.455	0.466	0.212	4
Over excavation	0.500	0.386	0.178	5
Lacking reinforcement bars	0.545	0.307	0.167	6
Leaking concrete from joints of the formwork	0.500	0.329	0.165	7
Damaging formwork materials due to irregular shapes with non-standard sized modular panels	0.455	0.318	0.145	8
Using inappropriate head for poker vibrators	0.591	0.239	0.141	9

Table 4.21 (continued)

Item	**Frequency Index (FI)**	**Severity Index (SI)**	**Importance index FI × SI**	**Rank**
Collapsing excavation walls	0.182	0.739	0.134	10
Wasting the reinforcement bars by wrong workmanship	0.273	0.488	0.133	11
Demolishing or repairing some parts of concrete due to non-conformance to the specification	0.136	0.705	0.096	12
Bad appearance of concrete surface caused by deformation of formwork	0.318	0.295	0.094	13
Falling formwork materials from top storeys that causes damage to them	0.273	0.341	0.093	14
Fabricating inaccurately dimensioned concrete elements	0.318	0.261	0.083	15
Displacement of formwork at the time of placing concrete	0.409	0.193	0.079	16
Appearing cracks at the corners of concrete elements	0.273	0.215	0.059	17

4.5.4 Time Effect of Rework Items

The influence of rework items on time delay is investigated and it is presented as importance index (IMP.I.) of rework items in this section. Otherwise the cost effect of excavation rework items, collapsing excavation walls has more influence on time delay than over excavation in this phase of construction (Table 4.22).

Table 4.22. Time effect of excavation rework items

Item	F.I.	S.I.	IMP.I.	Rank
Collapsing excavation walls	0.636	0.727	0.462	1
Over excavation	0.545	0.784	0.427	2

Lacking reinforcement bars has the most effect on time delay in phase of reinforcing. Remaining reinforcement bars at the end of construction is the least important item in time delay among reinforcing rework items which has a negligible effect on time delay due to rework (Table 4.23).

Table 4.23. Time effect of reinforcing rework items

Item	F.I.	S.I.	IMP.I.	Rank
Lacking reinforcement bars	0.318	0.216	0.069	1
Wasting the reinforcement bars by wrong workmanship	0.273	0.204	0.056	2
Changing the designed steel bar diameters due to unavailability	0.182	0.170	0.031	3
Remaining reinforcement bars at the end of construction	0.136	0.034	0.005	4

The effect of formwork rework items on time delay is provided in Table 4.24.

Table 4.24. Time effect of formwork rework items

Item	F.I.	S.I.	IMP.I.	Rank
Falling formwork materials from top storeys that causes damage to them	0.500	0.489	0.245	1
Fabricating inaccurately dimensioned concrete elements	0.500	0.477	0.239	2
Damaging formwork materials due to irregular shapes with non-standard sized modular panels	0.455	0.454	0.207	3
Appearing cracks at the corners of concrete elements	0.500	0.284	0.142	4
Bad appearance of concrete surface caused by deformation of formwork	0.545	0.227	0.124	5
Displacement of formwork at the time of placing concrete	0.455	0.182	0.083	6
Leaking concrete from joints of the formwork	0.591	0.114	0.067	7

Table 4.25 shows the effect of concrete work rework items on time delay.

Table 4.25. Time effect of concrete-work rework items

Item	F.I.	S.I.	IMP.I.	Rank
Demolishing or repairing some parts of concrete due to non-conformance to the specification	0.273	0.795	0.217	1
Allocating inappropriate concrete materials	0.409	0.182	0.074	2
Forming cold joint due to mismanagement of concrete delivering to the site	0.318	0.193	0.061	3
Using inappropriate head for poker vibrators	0.273	0.136	0.037	4

Table 4.26 illustrates the influence of rework items on time delay in constructing a reinforced concrete structure.

Table 4.26. Time effect of rework items in constructing a reinforced concrete structure

Item	**Frequency Index (FI)**	**Severity Index (SI)**	**Importance index FI × SI**	**Rank**
Collapsing excavation walls	0.636	0.727	0.462	1
Over excavation	0.545	0.784	0.427	2
Falling formwork materials from top storeys that causes damage to them	0.500	0.489	0.245	3
Fabricating inaccurately dimensioned concrete elements	0.500	0.477	0.239	4
Demolishing or repairing some parts of concrete due to non-conformance to the specification	0.273	0.795	0.217	5
Damaging formwork materials due to irregular shapes with non-standard sized modular panels	0.455	0.454	0.207	6
Appearing cracks at the corners of concrete elements	0.500	0.284	0.142	7
Bad appearance of concrete surface caused by deformation of formwork	0.545	0.227	0.124	8

Table 4.26 (continued)

Item	**Frequency Index (FI)**	**Severity Index (SI)**	**Importance index FI × SI**	**Rank**
Displacement of formwork at the time of placing concrete	0.455	0.182	0.083	9
Allocating inappropriate concrete materials	0.409	0.182	0.074	10
Lacking reinforcement bars	0.318	0.216	0.069	11
Leaking concrete from joints of the formwork	0.591	0.114	0.067	12
Forming cold joint due to mismanagement of concrete delivering to the site	0.318	0.193	0.061	13
Wasting the reinforcement bars by wrong workmanship	0.273	0.204	0.056	14
Using inappropriate head for poker vibrators	0.273	0.136	0.037	15
Changing the designed steel bar diameters due to unavailability	0.182	0.170	0.031	16
Remaining reinforcement bars at the end of construction	0.136	0.034	0.005	17

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Rework is one of the major determinants of construction productivity. This thesis aimed at investigating the reworks in constructing reinforced concrete structure by determining the wasting cost and time delay due to rework, identifying rework factors, and exploring the frequency and effect of rework items in project cost and time.

The methodology used in this study was case study and questionnaire survey. The case study project was three blocks of 8-storeys residential buildings with reinforced concrete structure and the total construction area of 12000 square meters. Excavation was done by owner and the construction of reinforced concrete structure was done by main contractor. Main contractor hired subcontractors for execution. The data collection was through the personal observation and also interviews of the civil engineer supervisors. In addition to the case study, a questionnaire survey was conducted among medium to large size (ranged between 5000 to 16000 square meters of construction area) reinforced concrete construction projects. 22 construction projects contributed to this survey.

The results of case study project showed that the cost of rework is 1.85% of the construction cost and time delay due to rework is 4.1% of the duration of constructing reinforced concrete structure. After analyzing the data, similar results were obtained from the questionnaire survey. Survey results indicated that, around 2.1% of the construction cost and 5.18% of the construction time was wasted due to rework.

In the case study project, the share in rework cost was determined as: 46% of contractor, 37% of owner, and 17% of consultant. The relative results of the questionnaire survey indicated that, contractors had almost 49% of the share of rework cost, owners had around 31%, and the share of consultants in rework cost was almost 20%.

Frequency and cost and time severity of 17 common rework items during the construction of reinforced concrete structure consisted of 4 phases of construction were investigated in the survey. Factor analysis was performed to find the correlation among the rework items of each phase of construction. According to the results of questionnaire survey, changing the designed steel bar diameters due to unavailability, using inappropriate head for poker vibrators, and lacking reinforcement bars were the most three frequent rework items, respectively.

The results of factor analysis demonstrated that, 17 investigated rework items can be categorized into 4 components and each component represents one phase of the constructing reinforced concrete structure. These phases are: formwork which represented 33.11% of variance, reinforcing with 21.58%, concrete work with 13.45%, and excavation with 6.89% of represent of variance.

Cost and time effect of rework items were also investigated in this research. For this purpose, importance index of each rework item was calculated by multiplying frequency index and severity index which explained in the methodology chapter. The rework items of each phase of construction and the total rework items were ranked by their importance in cost and time effect separately. Referring to the results, allocating inappropriate concrete materials, changing the designed steel bar diameters due to unavailability, and forming cold joint due to mismanagement of concrete delivering to the site were the most three effective rework items in cost waste due to rework. Collapsing excavation walls, over excavation, and falling formwork materials from top storeys that causes damage to them were three items with the most influence on time delay due to rework.

The results of this study showed that almost half of rework cost in constructing reinforced concrete structure caused by contractors. Lack of construction experience, hiring contractors just based on the offered price, lack of coordination among contractors or between contractor and management team, and lack of sufficient supervision resulted in high level of contractor's share in cost of rework.

The second most effective factor in cost of rework was owners which caused around one third of wasting cost due to rework. Trying to keep the cost down by hiring an inexperienced contractors and not hiring the construction manager, involving in the construction works directly instead of assign it to the consultant, the various number of the owners in one project and interfering all of them in construction instead of choosing one representative, and changing the building plan or materials were the main reasons.

The least effective factor in rework cost was consultants. Some of the reasons that they caused wasting cost due to rework were: having uncertainties about their missions, having ambiguities in case of contracts, being unfamiliar with laws, lack of commitment to their duties, and poor communication.

In total, the rework items of excavation phase of construction were the least frequent items among 4 phases, they were in the middle of cost effective items, and they had the most effect on time delay. The formwork phase had the most number of investigated items (7 out of 17) but they ranged as the low important items in cost and medium to high important items in time. The number one of most frequent rework item was from reinforcing phase but totally the rework items of this phase were medium to high frequent and they had a medium influence on cost and low influence on time. Finally, the concrete work's rework items ranged as medium to high important items in cost and medium important in time.

To reduce the frequency of rework and eliminate cost wasting and time delay due to rework the following precautions are recommended:

- Owners should avoid involving in construction works such as holding tender directly. It is recommended to assign them to the consultant or representative who is familiar with technical issues.
- Owners should hire the construction manager to do cost and time management, organize the contracts, select the suitable construction methods or materials and observe the construction process.
- Having a fulltime supervisor in the project site to prevent the rework or make the wrong implemented works correct on time is recommended.

- Preventing reworks to happen by considering the technical competency of the contractors. Most of the time the best contractor to select is not who offered the lowest price as there are hidden costs such as rework cost with them.
- Owners should avoid of making changes in plan or materials at the time construction.
- Try to make the missions and possibilities of the contractors, consultant, and management team clear by writing proper contracts.
- Designers are recommended to use one number of steel bars instead of using similar numbers.
- Do not utilizing substandard materials in construction.
- Managing the available reinforcement bars and avoid of buying more or less amount of bars than are needed for construction.
- Protecting excavation walls from falling by constructing a proper structure.
- Defining the excavation area clearly before excavation.
- Hiring trained workmanship.
- Managing the concrete resources by defining the required number of trucks based on the capacity of the concrete source.
- Providing concrete from trusted source.

5.2 Recommendations

It is recommended to do further studies on rework in the following areas:

1. Cost and time impact of rework in construction industry.
2. Investigating rework items and factors in construction.
3. Cost and time impact of rework in constructing different types of structure and make comparison.

4. Direct and indirect costs of rework in construction projects.
5. Effects of procurement method on rework in construction.
6. Influences of quality management systems on rework in construction projects.

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APPENDIX

Questionnaire

1. This questionnaire is prepared to find out the cost and time impacts of reworks in building a reinforced concrete structure.
2. The construction phases that this questionnaire focuses on are:
   -Excavation
   -Foundation
   -Structure (columns, beams, shear and retail walls)
   -Slabs

Cost of rework in percent of construction cost	Delay due to rework in percent of construction time

Determine the share of these factors in rework cost (by percent)		
Contractor	Owner	Consultant

Rework item	**Did the rework item happen?** **Yes**	**NO**	**Severity of rework item on cost (0 means no severe and 4 extremely)** **1**	**2**	**3**	**4**	**Severity of rework item on time (0 means no severe and 4 extremely)** **1**	**2**	**3**	**4**
Over excavation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Rework item	**Did the rework item happen?**		**Severity of rework item on cost (0 means no severe and 4 extremely)**				**Severity of rework item on time (0 means no severe and 4 extremely)**			
	Yes	**NO**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Collapsing excavation walls	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Appearing cracks at the corners of concrete elements	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Displacement of formwork at the time of placing concrete	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Falling formwork materials from top storeys that causes damage them.	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Bad appearance of concrete surface caused by deformation of formwork	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fabricating inaccurately dimensioned concrete elements	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Damaging formwork materials due to irregular shapes with non-standard sized modular panels	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Leaking concrete from joints of the formwork	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Changing the designed steel bar diameters due to unavailability	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Wasting the reinforcement bars by wrong workmanship	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Rework item	Did the rework item happen?		Severity of rework item on cost (0 means no severe and 4 extremely)				Severity of rework item on time (0 means no severe and 4 extremely)			
	Yes	NO	1	2	3	4	1	2	3	4
Remaining reinforcement bars at the end of construction	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lacking reinforcement bars	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Using inappropriate head for poker vibrators	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Forming cold joint due to mismanagement of concrete delivering to the site	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Allocating inappropriate concrete materials	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Demolishing or repairing some parts of concrete due to non-conformance to the specification	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐