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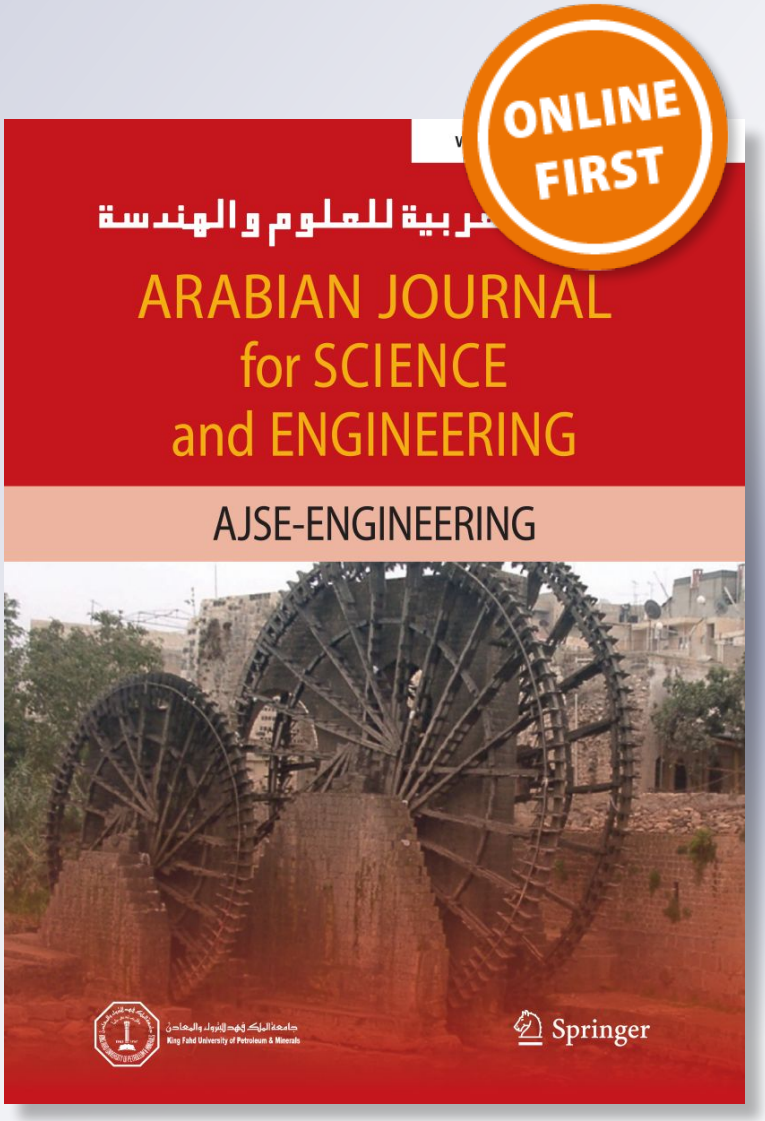
Arabian Journal for Science and Engineering

ISSN 2193-567X

Arab J Sci Eng
DOI 10.1007/s13369-017-2850-2



Springer

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DOI 10.1007/s13369-017-2850-2

RESEARCH ARTICLE - CIVIL ENGINEERING

Diagnose the Causes of Cost Deviation in Highway Construction Projects by Using Root Cause Analysis Techniques

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Received: 18 April 2017 / Accepted: 4 October 2017

Abstract The root cause analysis techniques are a good choice to be adopted to diagnose the root causes of cost deviation in highway projects. Many root cause analysis tools have emerged from the literature as generic standards for identifying root causes such as Fishbone diagram, Pareto diagram, and the 5-Why analysis. This study diagnosed twenty causes of cost deviation in highway projects in Republic of Iraq which they divided into three main groups (planning causes, designing causes, and execution causes). Pareto analysis showed that eleven causes out of twenty causes represent the most important causes of cost deviation, these eleven causes had been filtered by 5-Why analysis, this analysis concluded that the unavailability of enough information about the project is a root cause for planning causes group, while the clarity lack of the owner requirements is a root cause for designing causes group and finally, the poor efficiency of the administrative staff is a root cause for execution causes group.

Keywords Highway projects · Cost deviation · Root cause analysis techniques · Fishbone diagram · Pareto diagram · 5-Why analysis

Abbreviations

RCA	Root causes analysis
ARCTM	Accident root causes tracing model
RAF	Rank agreement factor
PA	Percentage agreement
PD	Percentage disagreement

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1 Introduction

It is difficult to visualize that there is a construction project is performed without happening a cost deviation or without failures during the execution phase that may occur due to poor cost management, poor monitoring, or poor supervision. Also, highway projects are undertaken in a complex environment. And there are no reliable data and trusted information when estimating cost items.

One of the most important obstacles and difficulties experienced by estimators to estimate costs in the conceptual stage in the Republic of Iraq [1]:

(1) The absence of an integrated database on previously implemented construction projects.
(2) Do not use modern and advanced tools in estimating the costs of construction projects.
(3) Lack of interest in engineering alternatives in the planning, design and execution of construction projects.

The basic problem in cost estimation for highway projects by using the popular cost estimation formulas or methods is that the result of these methods is deterministic (single point estimation). But after the project completion, the actual cost deviation from the estimated is noticed, this may be return to many reasons and the construction conditions are un-trusted since it is unstable. So root causes analysis is coming to deal with this problem according to its methodology.

On the other hand, root causes analysis culture is absent in the Iraqi construction sector in particular. Root causes analy-

Published online: 23 October 2017

sis is a concept which is used in various disciplines especially engineering so it may be useful in projects management as general or in cost management in particular.

The objectives of this paper are to identify and diagnose the causes of cost deviation in highway project under different groups (planning reasons, designing reasons, and execution reasons), determine the relative importance of theses causes, determine the relative importance of each group, and provide logical solutions that help in the implementation of highway project within budget without any deviation in cost.

2 Research Question

Only one important question raised in this study is: "Is root cause analysis techniques can be applied in highway projects management in order to control the cost deviation?" In order to answer this question, must be indicating the research problem.

3 Research Problem

The research problems are summarized by the following points based upon the review of the literature and some interviews with senior engineers:

(1) There is a weakness in estimation of the cost of the highway projects because the current available techniques are poor and suffer some of disadvantages such as traditional, aged, slow and uncertain techniques. Besides the need for modern efficient cost estimation techniques which have several advantages such as modern, fast, accurate, flexible and easy to use better techniques. Therefore, the application of root cause analysis techniques, as a modern technique in construction industry, is necessary to ensure successful management, and many of construction companies feel with the need of such technique in project management.
(2) There is a weakness in documenting the cost records of past projects and the absence of data on a highway project management.
(3) The importance of highways for Iraq as a developing country, because;
    (a) No civilized society can be survived without highways.
    (b) Highway has a great cultural value.
    (c) Highway has the most important role to play in the defines of the country.
    (d) Highway is the symbol of a country's progress.
    (e) Highway development and transport have the highest employment potential of all economic activities.

4 Research Importance

It can be summarized the importance of this research, as follows:

(1) This research highlights on the cost deviation for highway projects. Since this type of the projects have a great importance among other types of the construction projects.
(2) It provides a true vision of the difficulties faced by project managers and planners, when applying the methodology of cost management in highway projects, in order to overcome these obstacles and reduce them,
(3) Encourage researchers, lecturers and academics to conduct further researchers and integrate with the results of the current study. The motivation of this study is the limited number of research in the area of cost deviation with regard to highway projects, and the need for a better cost management in highway project.

5 Research Limits

This research limited to the following limits:

(1) Time limits: gathering data were implemented in 2016.
(2) Spatial limits: This study was conducted on highway project in Republic of Iraq.

6 Research Methodology

A three-step study methodology is conducted, in order to obtain the objective of the study:

(1) Literature review.
(2) Questionnaire and Personal interviews with engineers of exact specialization in highway engineering or at least of past experience in highway projects, this step had explained in reference [2].
(3) Statistical analysis.

The researcher used same procedure follow-up by Al-Zwainy and Neran [3], Al-Zwainy et al. [4] and [5], for exploring the literature survey. A comprehensive literature review was conducted to provide the previous research studies related to the project management methodology from previous literature in local and international journal papers,

research reports, conference proceedings, theses, dissertations, and internet publications.

7 Previous Studies

In 1998, Jimmie [6], investigated the root causes of construction accidents. One source of information on the causes associated with many serious injuries and fatalities is maintained by the Occupational Safety and Health Administration (OSHA). The study presents recommendations on how the OSHA reports could be made more meaningful. First, injuries had been coded into one of the 20 possible cause categories, rather than the traditional five groups of falls, struck-by, electric shock, caught in/between, and other. Additional or secondary cause codes also were developed. The results could then be utilized to focus greater attention on those areas for which modifications in the regulations are warranted and it would be more helpful to the construction industry by emphasizing the major causes of serious accidents.

In 2000, Tariq [7] investigates root causes of construction accident. Their study presents an accident root causes tracing model (ARCTM). ARCTM proposes that accidents occur due to three root causes: (1) failing to identify an unsafe condition that existed before an activity was started; (2) deciding to proceed with a work activity after the worker identifies an existing unsafe condition; and (3) deciding to act unsafe regardless of initial conditions of the work environment. In addition, ARCTM emphasizes the need to determine how unsafe conditions exist before or develop after an activity is started and proposes that these unsafe conditions are due to four causes: (1) management actions/inactions; (2) unsafe acts of worker or co-worker; (3) non-human-related event(s); (4) an unsafe condition that is a natural part of the initial construction site conditions.

In 2006, Tommy et al. [8], aimed first, at gathering the perceptions of civil construction practitioners on how significant are the causes of delay; and, second, investigating whether the suggestions as stated in the report of the Construction Industry Review Committee (the committee comprises members with good standing and knowledge in the construction and related fields as well as those from other professions who are responsible for examining the current state of the construction industry in terms of its output quantity, the quality of work, its environmental friendliness, site safety, its workforce and the system of supervision) are applicable to and effective at mitigating the corresponding delays with reference to a ranking order established using the mean score method. The extent of the differences in perception among the different respondent groups on these two issues was also examined using the rank agreement factor (RAF), percentage agreement (PA), and percentage disagreement (PD). This study had been applied on six projects. A strong consensus was found between the client and consultant groups on the significance of the various causes of delay (PA = 74%) and the effectiveness of mitigation measures (PA = 67%) compared with the other pairs of groups.

In 2014, Yehiel [9], examines cost overruns phenomenon impact on the construction industry as a worldwide problem, identifies its root causes, ranks them (on a local basis), and analyzes them. Firstly, the study had been gathered 146 potential causes from the international professional literature as well as from prominent local experts. Finally, they were filtered and merged into merely 15 independent universal root causes. These were further investigated through a cross-sectional survey among 200 local practitioners who ranked the 15 universal root causes according to their conceived local importance and influence on cost overruns. The survey revealed that three most important causes out of 15 are, cause number 1 premature tender documents; cause number 2 is too many changes in owners' requirements or definitions; and cause number 3 is tender-winning prices are unrealistically low (suicide tendering).

In 2016, Faiq and Reem [2] investigated the cost management status of the highway construction projects in Iraq. Survey included investigate and evaluation the reality of cost planning and control and determine the causes of construction cost deviation. Causes of cost deviation had been investigated and collected by conducting the personal interviews and questionnaire with the sites engineers and by reviewing the previous literature. Iraqi Road and Bridge Directorate was selected as a sample study. It is worth to mention that the statistical analysis has been conducted by using the SPSS program (version 20). Cost deviation reasons had classified into three groups by the researchers, which are planning reasons, designing reasons, execution reasons. Planning reasons classification had taken a relative importance equal to 2.7%, designing reasons classification had taken a relative importance equal to 3% and execution reasons classification had taken a relative importance equal to 2.45%.

8 Root Cause Analysis Concept

Root cause analysis (RCA) is a useful process for understanding and solving a problem. RCA is a popular and often-used technique that helps people answer the question of why the problem occurred in the first place. It seeks to identify the origin of a problem using a specific set of steps, with associated tools, to find the primary cause of the problem, so that you can:

(a) Determine what happened.
(b) Determine why it happened.

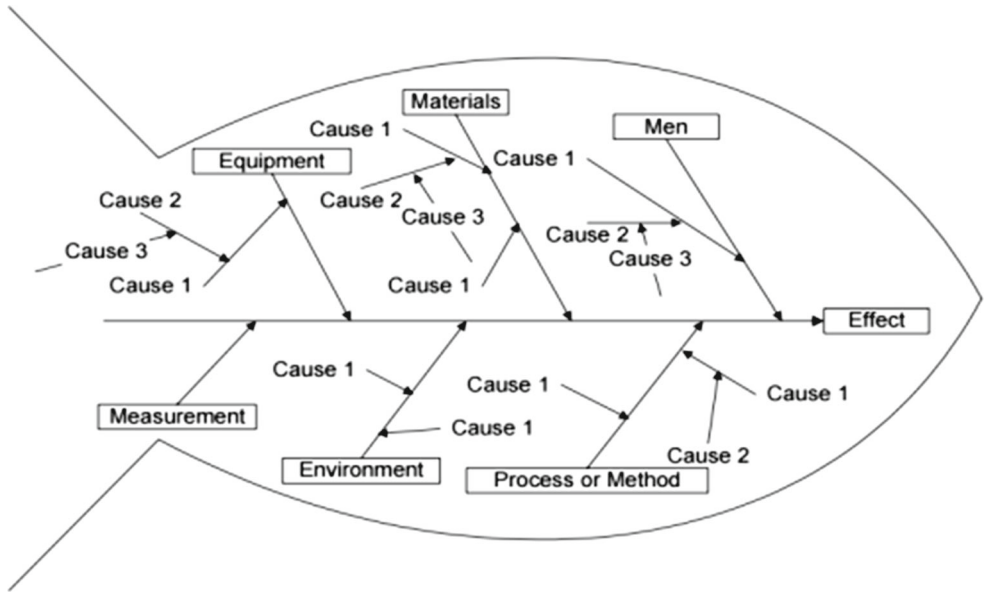

Fig. 1 Cause and effect diagram form [11]

(c) Figure out what to do to reduce the likelihood that it will happen again.

Root cause analysis (RCA) is a valuable management tool that can be readily learned by managers as well as frontline personnel. These techniques can be of enormous value. They capture both the big-picture perspective and the details. They facilitate system evaluation, analysis of need for corrective action, and tracking and trending. Regarding trending, managers will be able to determine how often a particular error occurs. This analysis is as useful and perhaps even more efficacious. The technique can be applicable not only to engineering, also they applicable to other disciplines [10].

It is a method that is used to address a problem or nonconformance in order to get to "the root cause" of the problem. It is used to eliminate or mitigate the cause and prevent the problem from recurring. RCA is simply the application of a series of well-known common sense techniques which can produce a systematic, quantified, and documented approach to the identification, understanding, and resolution of underlying causes [11].

Root cause analysis is not merely an arbitrary expression; rather, it is a systematic, formal, well-structured methodology, used as part of the total quality–management approach [9].

9 Root Cause Analysis Techniques

There are several tools of root cause analysis techniques for creative thinking such as, Fishbone diagrams, Mind mapping, Pareto analysis, causal tree, brainstorming, nominal group technique, metaphorical thinking, and 5-Why analysis. The researcher will focus on Fishbone diagrams, Pareto diagrams, and 5-Why technique.

9.1 Fishbone Diagrams

Fishbone diagram was devised by Professor Kaoru Ishikawa, a pioneer of quality management, in 1960s. The technique was then published in his book in 1990, "Introduction to Quality Control.", the diagrams are known as Ishikawa diagrams, cause and effect analysis or Fishbone diagram because a completed diagram can look like the skeleton of a fish [12]. This tool is used to come up with new ideas like a brainstorming, but in a more balanced way [13]. A cause and effect diagram offers a structured approach to the search for the possible causes(s) of a problem. This tool helps to organize problem-solving efforts by identifying *categories* of factors that might be causing problems. Often this tool is used after Pareto or brainstorming sessions to organize the ideas generated [14]. This type of diagram identifies all the potential factors that could contribute to a problem. Once all the desired information had been captured and represented by fishbone diagram, this can help in finding resolutions [11]. Figure 1 is an example which totally represents this technique.

9.2 Pareto Diagram

Pareto analysis is a technique for focusing attention on the most important problem areas. The Pareto concept, named after the nineteenth century by Italian economist Vilfredo Pareto, is that relatively few factors generally account for a large percentage of the total cases (e.g., complaints, defects,

and problems). The idea is to classify the cases, according to the degree of importance, and focus on resolving the most important, leaving the less important [14]. Pareto analysis is a formal technique for finding the changes that will give the biggest benefits [11].

9.3 5-Why Technique

It is one of the many brainstorming methodologies of asking "why" five times repeatedly to help in identifying the root cause of a problem. If a problem is repeatedly questioned, each time an alternative solution comes out which is linked to the root cause. However, asking why may be continued till getting an agreeable solution. Five is an arbitrary figure. The theory is that after asking "why" five times one is likely to arrive at the root cause [15].

10 Diagnose the Root Causes for Cost Deviation in Highway Project

In order to identify and analyze the root causes for cost deviation in highway project, a survey research approach was adopted to determine the weight of each cause, these weights are important to apply the root cause analysis. In this study, the researcher was also adopted the literature review, questionnaire and personal interviews with experts who were basically selected depending on their experience and qualification. The causes of the cost deviation in highway project under different groups had been deduced (planning causes, designing causes, and execution causes) based on results obtained from study (Faiq and Reem [2]), and as it is shown in Table 1.

Table 1 Causes of cost deviation in highway projects

Cost deviation groups (main causes)	Symbols	Secondary causes	Symbols
Planning reasons	R1	The unsuitability of the contracting type with project type	R11
		The unsuitability of the execution manner	R12
		Unavailable of enough information about the project	R13
		Poor contractor selection	R14
		Lack of planning for inflation or changing currency rates	R15
Designing reasons	R2	Clarity lack of the owner requirements	R21
		Obscurity of specifications and conditions	R22
		Obscurity of plans and designs	R23
		Inaccurate bills of quantities	R24
Execution reasons	R3	Change orders	R31
		Poor efficiency of the administrative staff	R32
		Using poor execution manners	R33
		Productivity rate fluctuation of labor and equipments	R34
		Accidents during the execution	R35
		Fluctuation of materials prices	R36
		Labor wages fluctuation	R37
		Renting and purchasing cost fluctuation of equipments and machines	R38
		Inaccurate selection of machine and equipments	R39
		Project duration reduction	R310
		Project duration exceeded on the specified scheduling	R311

10.1 Secondary Planning Reasons Analysis

Planning causes group (R1) consists of five causes which they previously arranged in Tables 1 and 2 shows the weights (note: these weights represent the field survey results), relative importance and ranking of each factor under planning group. Figures 2 and 3 show the fishbone diagram and Pareto chart for this group analysis, respectively.

From Pareto chart, it is concluded that poor contractor selection (R14), unavailable of enough information about the project (R13) and the unsuitability of the execution manner (R12) are responsible for 78% of cost deviation due to secondary planning causes in highway projects. So the targeting these top causes, 78% of the problem (cost deviation due to secondary planning causes in highway projects) will be resolved.

Table 2 Secondary planning causes weights, relative importance and rank

Main cause	Secondary causes	Weights of secondary causes	RI (%)	Ranking
Planning reasons (R1)	R11	67	20.57	4
	R12	68.75	21.11	3
	R13	81.5	25.02	2
	R14	84	25.78	1
	R15	24.5	7.52	5
$\sum$		325.75	100	

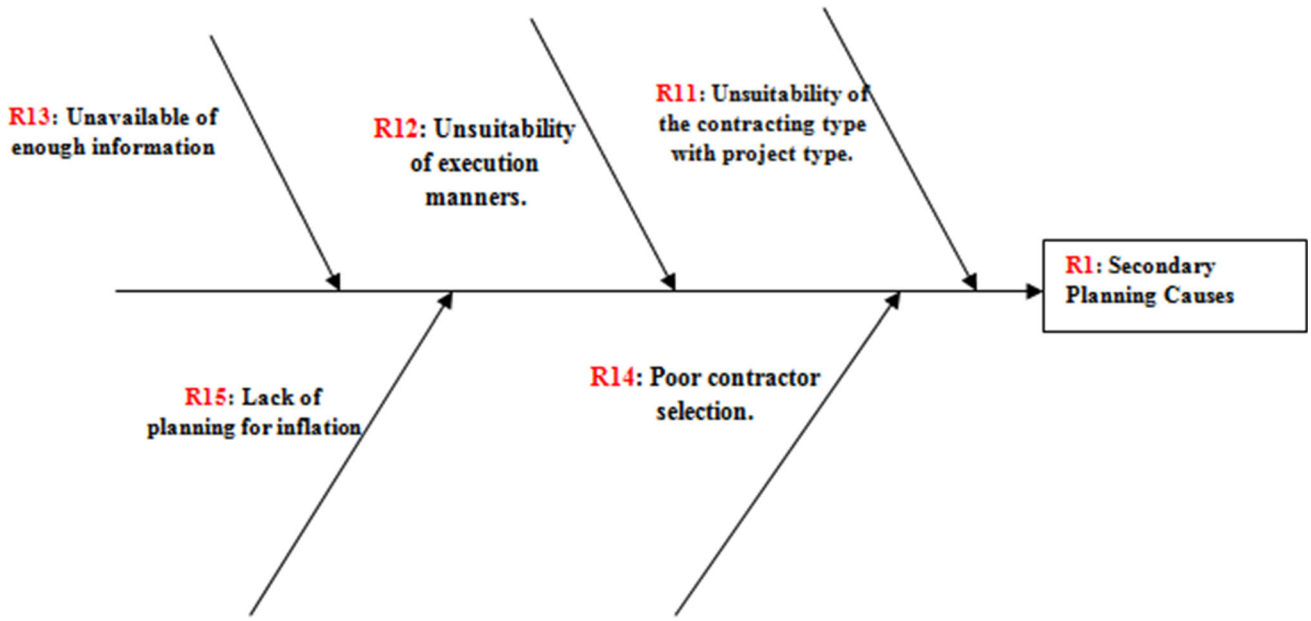

Fig. 2 Fishbone diagram for secondary planning causes

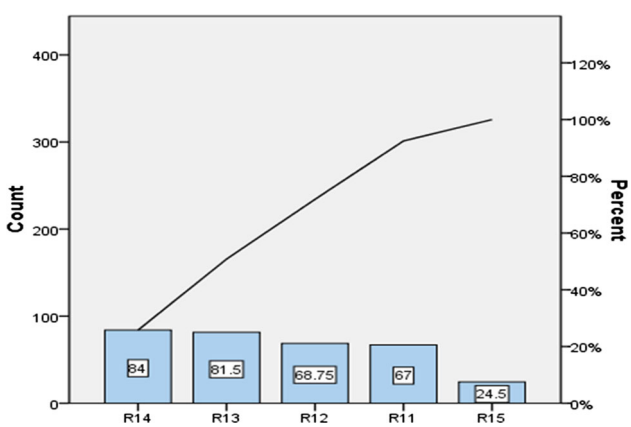

Fig. 3 Pareto chart for secondary planning causes

Table 3 Secondary designing causes weights, relative importance and rank

Group name	Secondary causes	Weights of secondary causes	RI (%)	Ranking
Designing reasons (R2)	R21	72.75	25.91	3
	R22	72.25	25.75	4
	R23	77.75	24.25	1
	R24	77.25	24.08	2
$\sum$		300	100	

10.2 Secondary Designing Reasons Analysis

Designing causes group (R2) consists of four causes which they previously arranged in Tables 1 and 3 shows the weights, relative importance and ranking of each factor under designing group. Figures 4 and 5 show the Fishbone diagram and Pareto chart for this group analysis, respectively:

From Pareto chart, it is concluded that obscurity of plans and designs (R23), inaccurate bills of quantities (R24) are responsible for 64% of cost deviation due to secondary designing causes in highway projects. So the targeting these top causes, 64% of the problem (cost deviation due to secondary designing causes in highway projects) will be resolved.

10.3 Secondary Execution Reasons Analysis

Execution causes group (R3) consists of eleven causes which they previously arranged in Tables 1 and 4 shows the weights and ranking of each factor under execution group. Figures 6 and 7 show the Fishbone diagram and Pareto chart for this group analysis, respectively.

From the above Pareto chart, it is concluded that change orders (R31), poor efficiency of the administrative staff (R32), using poor execution manners (R33), project duration reduction (R310), fluctuation of materials prices (R36), project duration exceeded on the specified scheduling (R311) are responsible for 68% of cost deviation due to secondary execution causes in highway projects. So the targeting these top causes, 68% of the problem (cost deviation due to secondary execution causes in highway projects) will be resolved.

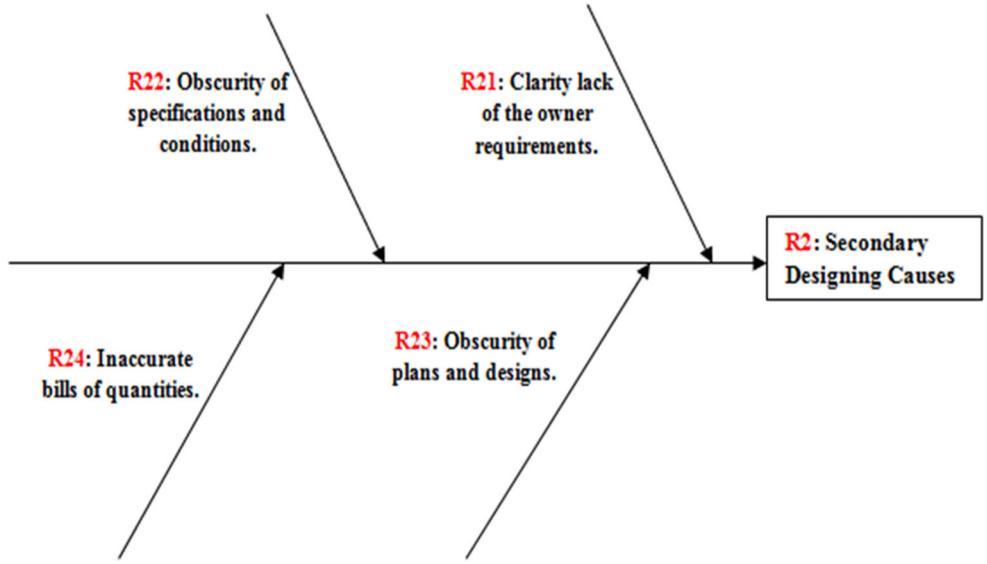

Fig. 4 Fishbone diagram for secondary designing causes

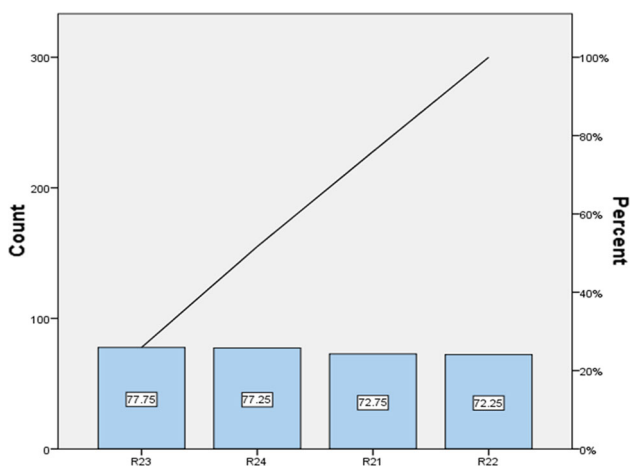

Fig. 5 Pareto chart for secondary designing causes

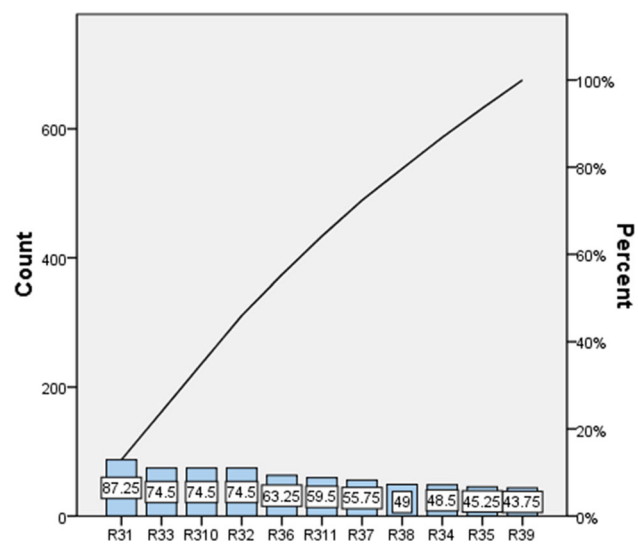

Fig. 7 Pareto chart for secondary execution causes

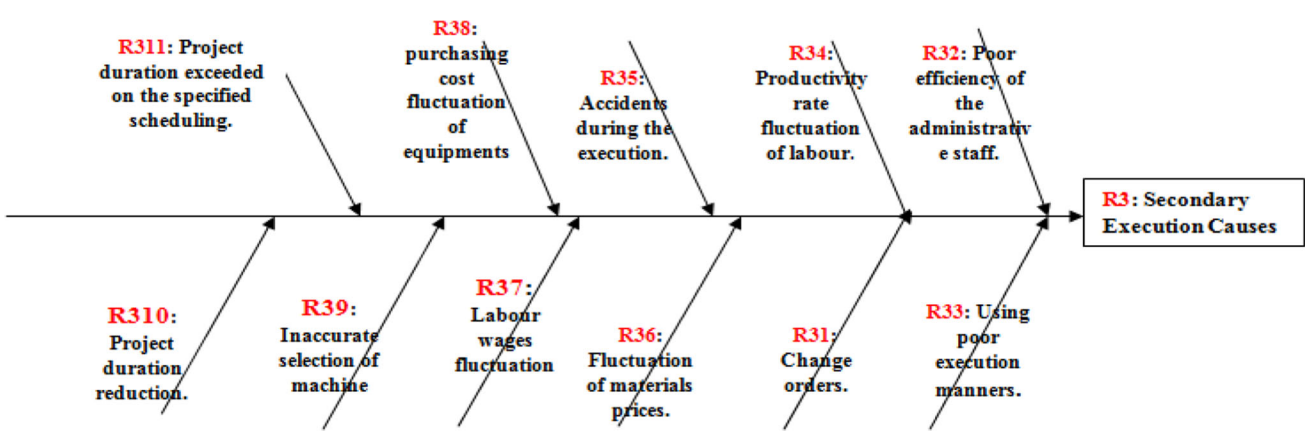

Fig. 6 Fishbone diagram for secondary execution causes

Table 4 Secondary execution causes weights, relative importance and rank

Main cause	Secondary causes	Weights of secondary causes	RI (%)	Ranking
Execution reasons (R3)	R31	87.25	12.91	1
	R32	74.5	11.02	2
	R33	74.5	11.02	3
	R34	48.5	11.0	9
	R35	45.25	9.36	10
	R36	63.25	8.81	5
	R37	55.75	8.25	7
	R38	49	7.26	8
	R39	43.75	7.17	11
	R310	74.5	6.69	4
	R311	59.5	6.48	6
$\sum$		675.75	100	

10.4 Main Causes Analysis

Main causes of cost deviation in highway projects had been divided into three groups as previously shown, and Table 4 shows the weights, relative importance and ranking of each main cause group [planning reasons (R1), designing reasons (R2) and execution reasons (R3)]. Figures 8 and 9 show the fishbone diagram and Pareto chart for main group's analysis, respectively.

From the above Pareto chart, it is concluded that "planning causes group (R1)", and "designing causes group (R2)" are responsible for 80% of the problem occurring. So by targeting these 2 top causes, 80% of the problem (cost deviation in highway projects) will be resolved.

11 5-Why Technique Applying

5-Why analysis technique can be used individually or as a part of the Fishbone diagram. The Fishbone diagram helps to explore all potential or real causes that result the cost deviation in highway project. Once all inputs are established on the Fishbone, can be used the 5-Why technique to drill down to the root causes. Also, this technique is one of the simplest tools and easy to complete without statistical analysis.

In this study, the researchers used 5-Why technique for identifying the root causes of cost deviation in highway projects and resolving problems, as follows:

(1) Write down the specific problem and formalize the problem and describe it completely.

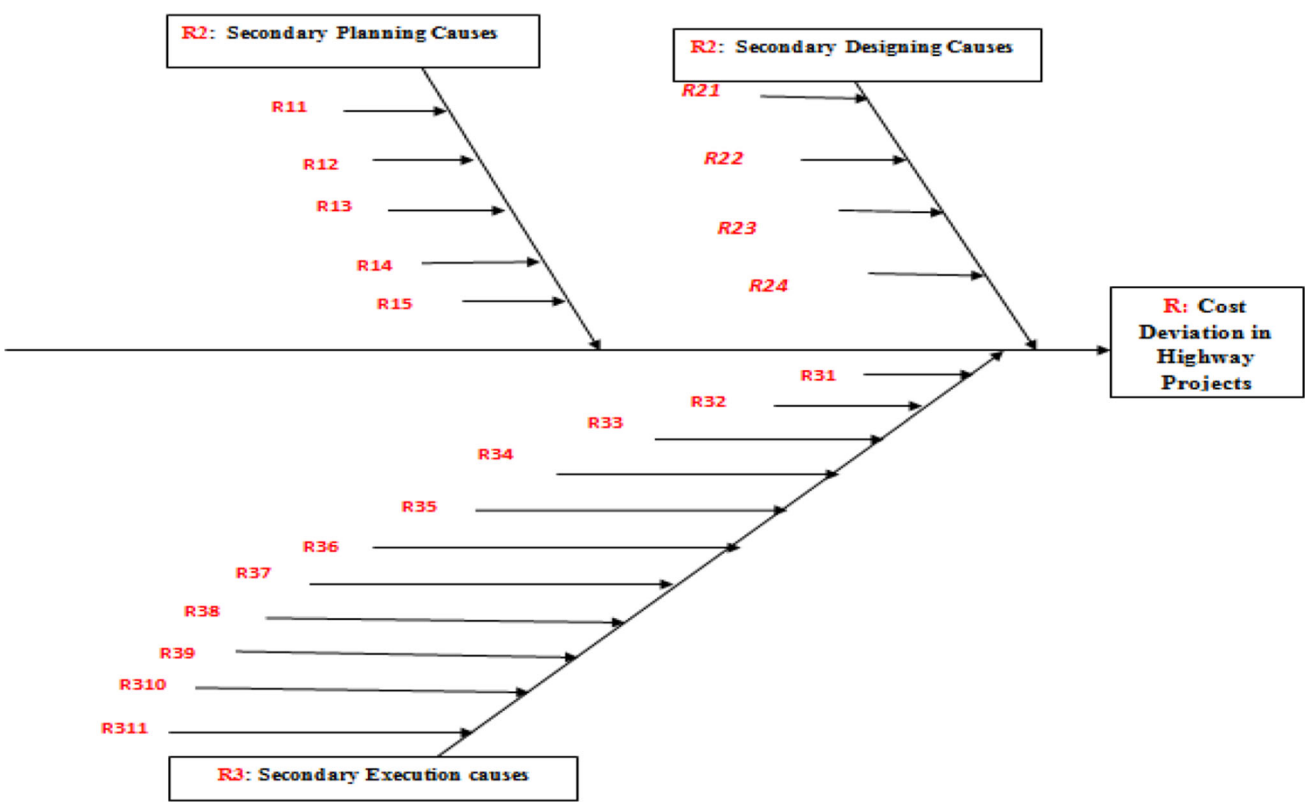

Fig. 8 Fishbone diagram for cost deviation causes in highway project

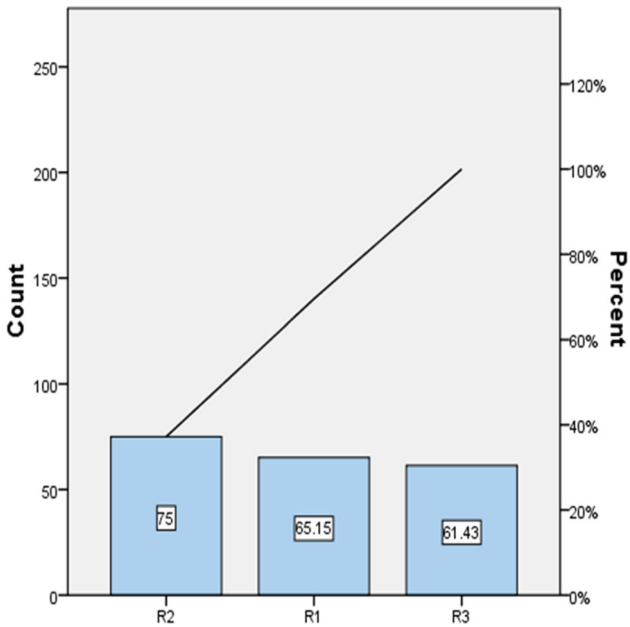

Fig. 9 Pareto chart for cost deviation problem causes in highway project

(2) Ask Why this problem (cost deviation in highway projects) happens and write the answer down below the problem. Table 5 shows the reasons that lead to this problem.
(3) If the answer just provided does not identify the root cause of the problem that wrote down in Step 1, ask Why again and write that answer down.

11.1 5-Why Analysis for Secondary Planning Causes

Table 6 contains the most important causes of planning causes group according to their calculated weight (note: the cause with weight less than 50 will be neglected). Figure 10 explains totally 5-Why analysis for this group to determine the root cause of planning causes group.

The root cause from secondary planning causes group according to 5-Why analysis is the unavailability of enough information about the project.

11.2 5-Why Analysis for Secondary Designing Cause

Table 7 contains the most important causes of designing causes group according to their calculated weight. Figure 11

Table 5 Main causes weights and relative importance and rank

No.	Code		Weights of secondary causes	Average weights of main causes	Relative importance RI (%)	Rank
	Main cost deviation causes groups	Secondary causes				
1	R1	R11	67	65.15	32.32	2
2		R12	68.75			
3		R13	81.5			
4		R14	84			
5		R15	24.5			
1		R21	72.75			
2	R2	R22	72.25	75	37.21	1
3		R23	77.75			
4		R24	77.25			
1	R3	R31	87.25	61.43	30.47	3
2		R32	74.5			
3		R33	74.5			
4		R34	48.5			
5		R35	45.25			
6		R36	63.25			
7		R37	55.75			
8		R38	49			
9		R39	43.75			
10		R310	74.5			
11		R311	59.5			
$\sum$	201.58	100%				

Table 6 Most important secondary planning causes according to their weights

Main cause	Secondary causes	Description	Weight	Ranking
Planning reasons (R1)	R11	The unsuitability of the contracting type with project type	67	4
	R12	The unsuitability of the execution manner	68.75	3
	R13	Unavailable of enough information about the project	81.5	2
	R14	Poor contractor selection	84	1

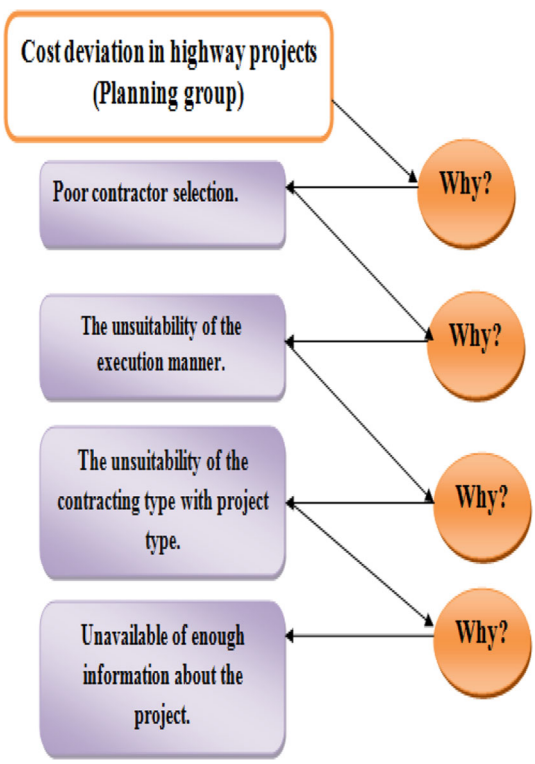

Fig. 10 5-Why analysis for secondary planning causes

explains totally 5-Why analysis for this group to determine the root cause of designing causes group.

The root cause from secondary designing causes group according to 5-Why analysis is the clarity lack of the owner requirements.

Table 7 Most important secondary designing causes according to their weights

Group name	Secondary causes	Description	Weight	Rank
Designing reasons (R2)	R21	Clarity lack of the owner requirements	72.75	3
	R22	Obscurity of specifications	72.25	4
	R23	Obscurity of plans and designs	77.75	1
	R24	Inaccurate bills of quantities	77.25	2

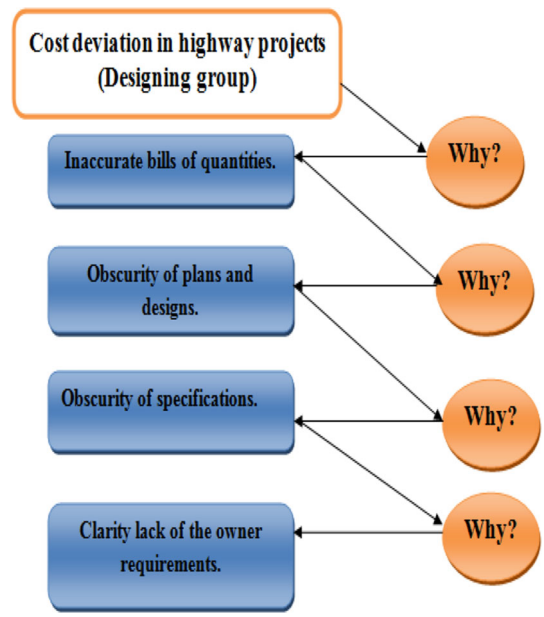

Fig. 11 5-Why analysis for secondary designing causes

11.3 5-Why Analysis for Secondary Execution Causes

Table 8 contains the most important causes of execution causes group according to their calculated weight, where the cause with weight less than 50 will be neglected. Figure 12 explains totally 5-Why analysis for this group to determine the root cause of execution causes group.

The root cause from secondary execution causes group according to 5-Why analysis is the poor efficiency of the administrative staff.

Finally, 5-Why analysis had been conducted for the obtained results from the 5-Why analysis for all secondary (planning, designing and execution) groups. Figure 13 explains this process totally. The final 5-Why analysis result said that the root cause for cost deviation in highway projects is the clarity lack of the owner requirements.

Table 8 Most important secondary execution causes according to their weights

Main cause	Secondary causes	Description	Weight	Ranking
Execution reasons (R3)	R31	Change orders	87.25	1
	R32	Poor efficiency of the administrative staff	74.5	2
	R33	Using poor execution manners	74.5	3
	R36	Fluctuation of materials prices	63.25	5
	R37	Labor wages fluctuation	55.75	7
	R310	Project duration reduction	74.5	4
	R311	Project duration exceeded on the specified scheduling	59.5	6

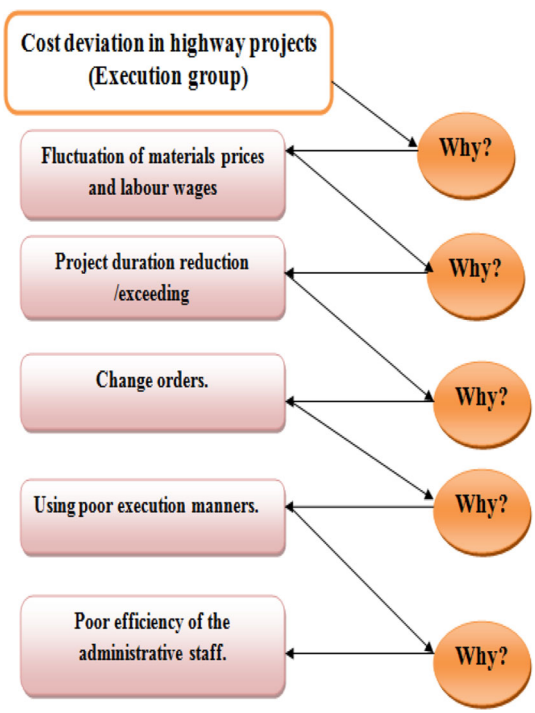

Fig. 12 5-Why analysis for secondary execution causes

12 Conclusions

Major conclusions can be summarized as follows:

(1) In this research, root cause identification methodology has been adopted to diagnose the causes of cost deviation in highway project under different groups such as planning group, designing group, and execution group. Root cause identification for project-related problems is a key and necessary step in the improvement and controlling of cost deviation. Fishbone diagram (FD), Pareto diagram (PD), and the 5-Why analysis used in this study to diagnose the causes of cost deviation in highway project in Republic of Iraqi.

(2) There are twenty cause that concentrated mostly in the execution group included eleven causes, and planning group with five causes. Minimum causes in designing group by four causes.

3) Pareto analysis showed that change orders (R31), poor efficiency of the administrative staff (R32), using poor execution manners (R33), project duration reduction (R310), fluctuation of materials prices (R36), project duration exceeded on the specified scheduling (R311), obscurity of plans and designs (R23), inaccurate bills of quantities (R24), poor contractor selection (R14), unavailable of enough information about the project (R13) and the unsuitability of the execution manner (R12), are main root causes of cost deviation in this type of projects, which they represent 11 out of 20.

4) Pareto results had been filtered more by applying 5-Why analysis, this analysis concluded that the unavailability of enough information about the project is a root cause for planning causes group, while the clarity lack of the owner requirements is a root cause for designing causes group and finally, the poor efficiency of the administrative staff is a root cause for execution causes group.

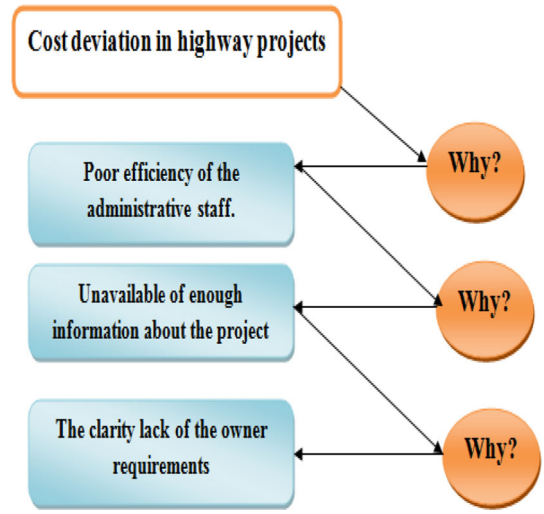

Fig. 13 Final 5-Why analysis

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