



A Budgeting Model for the Safety Unit of an Under Construction Metro Station in Tehran Using a Robust Optimization



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Seyed Mahdi Farshadnia ^a | Shirazeh Arghami ^{b,*} | Ali Shahab Safa ^c | † Framarz Majidi ^b

^a Department of Health, Safety & Environment Management, School of Public Health, Zanjan University of Medical Sciences, Zanjan, Iran.

^b Department of Occupational Health and Safety Engineering, School of Public Health, Zanjan University of Medical Sciences, Zanjan, Iran.

^c Department of Project Management Office of Pouyesh Dade Novin, Yazd, Iran.

*Corresponding author: Shirazeh Arghami

Department of Occupational Health and Safety Engineering, School of Public Health, Zanjan University of Medical Sciences, Zanjan, Iran, 4515786349. Tell: +98- 9121909978.

E-mail address: arghami@zums.ac.ir

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ABSTRACT

Background: The construction of metro lines is a high-risk project. Using a budget-based model for the safety units of metro construction projects can help safety managers to spend optimal budget allocation. The purpose of this study was to plan a budget model based on safety unit performance in an under construction metro station for better budget allocation using robust optimization.

Methods: To design this model, budget dimensions were identified by the experts and based on causes and costs of accidents in the past year. Then, constraints of metro workshops were considered. The next step was involved in determining the importance of each dimension. Finally, the budgeting model was designed using Gurobi software. In order to prove the proposed budgeting model, as a case study, the model was implemented in one of the metro workshops.

Results: Considering existing constraints, the model revealed that the budget should be at least 4.370.478.000 rials. Surprisingly, the predicted budget amount was less than the expended amount in the safety unit of the project. However, budget allocation to dimensions was dramatically different.

Conclusion: The results showed that the robust optimization budgeting was functionally and economically optimal. Moreover, there is a need for logical budget distribution.

1. Introduction

Over the last ten years, the construction of metros has been introduced as a major step forward for rapid economic and population growth, as well as urban development around the world [1, 2]. Metro line is a sustainable structure of public transportation as it has a significant contribution to reducing air pollution and traffic jam [3]. Currently, Tehran Metro Lines (5 lines) are ranked 21st in the world's metro transportation network. The agenda of the Tehran municipality has emphasized on increasing metro lines to at least ten lines [4].

Several accidents in constructing metro lines during the past years reveal numerous complexities and major risks in carrying out these projects. Since metro lines are usually located nearby residential areas, a few accidents with outside consequences have led to giving more attention to the safety of metro construction projects. The losses of these accidents may include substantial delays, costs, and deaths. Therefore, the role of safety units in these projects is vital [5]. Many parameters should be planned and re-planned to efficiently play this vital role. Among them, budgeting is probably the most crucial one.

Construction of a metro line is a long-lasting phase and usually takes a decade to complete. During this period, the rate of inflation may fluctuate beyond what was anticipated at the design phase. In addition, the loss of exposing unexpected events in this period can create more complicated conditions in terms of budgeting [3]. As Zhou et al. (2015) emphasized that large-scale infrastructures such as metro, airport, and bridge are known for their engineering complexities, which will increase construction safety risks [6] and may result in an overall cost of construction by up to 15 percent [7].

An effective project manager should complete the project with regard to quality, budget and time. Construction accidents usually delay projects. Therefore, reducing accidents and costs plays an important role in maintaining financial resources of the project [8]. Project management attempts to address its needs with limited resources; therefore, organizations have adopted the concept of budgeting and controlled it to meet their needs and fulfil their commitments to the stakeholders with minimal cost [9]. Budgeting leads an organization to reaching its goals and provides a potential assessment of the effects of changes that are difficult to apply [10]. Most managerial decisions are influenced by different factors. Managers always attempt to choose the best option among several options [11]. However, when decisions are required to examine several factors at once and together, making decisions becomes difficult [12]. For years, budgeting has been a powerful tool for managing organizations [13]. Budgeting has the advantage of being flexible in terms of the needs of decision makers [14]. Budgeting refers to processes that intend to communicate between the budgets allocated to programs or results. Due to the large number of factors affecting the budgeting method based on the performance and complexity of the budgeting environment, qualitative and mental methods cannot lead to an optimal decision making for the budget [15].

The use of mathematical models is important when complex activities and environment are complicated and uncertain. This causes confusion and inappropriate allocation of available resources. Optimizing is a mathematical method for determining the optimal allocation of resources according to its constraints and profit [16]. Although the first major optimization study was carried out in 1970 by Schiston, this method has, in fact, been developed over the last 15 years and is relatively new and has an active research background. Different publications on financial issues, energy, distribution chain of goods, care and health, engineering, planning, marketing, etc., show the high value of application and the use of robust optimization in various fields. In fact, the concept of this method and its techniques for working and working activities is very useful because it converts existing and available information into accurate and reliable mathematical formulas [17].

In most optimization methods, factors are assumed to be decisive, although the actual factors are usually uncertain based on their random nature, measurement errors, or other reasons. Robust optimization is an important way to optimize issues in uncertainty situations [18]. Robustness means that the output of the model should not be too sensitive to the exact values of the factors and inputs of the model [19]. The Delphi

method is widely used to collect data from experienced experts in a domain. This method is a group communication process whose goal is to achieve a convergence of views on a particular topic in the real world. In this way, by designing several key questions, in several steps, the experts' panel answers are collected [20]. The purpose of this study was to plan a budget model based on safety unit performance in an under construction metro station for better budget allocation using robust optimization.

2. Materials and Methods

The timeframe for this study was considered to be from beginning to end of 2016, and all information was gathered from a wide part of a line of Tehran Metro construction projects, including budget information and accident statistics for this year. The reason for this is the reconstruction of Tehran Metro Lines after several years of stopover in 2016 and an increase of more than 64 percent in this year, due to another better quality and more accurate recording of the information needed to study at this interval. In this study, a robust optimization method was used to design a safety budgeting model. The information obtained from the previous steps includes the Delphi technique information, details of the dimension, sub-dimension, and information of events, as inputs to the budgeting model (Table 1). After making the optimized optimization model, Gurobi software version 7.01 was used to solve the model.

2.1. Dimensions and sub-Dimensions

Due to the traditional and non-standardized budgeting in the metro safety unit, the budgeting measures affecting the performance of this unit that should be borne by them are not clear. Thus, in the first step, by using the experts' opinion and Delphi technique, the dimensions and sub-dimensions for the budget component of the safety unit were identified. In order to determine the dimensions and sub-dimensions of the safety unit budget and their importance, the Delphi technique along with opinions of 22 experts was used. In the first step, the Delphi technique was identified by a questionnaire on all their dimensions and sub-dimensions, and in the second step, a consensus was reached.

2.2. Importance of dimensions and Sub-dimensions

In the third step of the implementation of the Delphi technique, the importance of allocating funds to each of the dimensions and sub-dimensions was determined by the five-choice (very low, low, moderate, high, and very large) Likert scale. Each of the questions was answered from 1 to 5, respectively.

The records of the accidents of the safety unit were studied and analyzed. All accidents during 2016 related to the studied population (15 metro workshops) were extracted. The cause of the accidents, basic causes, direct cost and percentage of accidents were classified. The highest percentage of the cost of human-related accidents was 76.35%. These causes included accidents caused by the direct failure of the individual or authorities and managers for various reasons

such as human error, insufficient education to fully understand the tasks assigned, lack of familiarity with the devices and how to deal with them, lack of knowledge of workplace hazards and lack of attention to and compliance with safety regulations. Similar to the basic causes, inadequate monitoring and education were important factors in the occurrence of these accidents, which in the community studied each case, 53.67% and 33.69%, respectively, had a significant effect on the increase in the cost of the occurrence of accidents with human causes. The causes of other accidents, such as technical, environmental and organizational conditions, accounted for 23.65% of the accidents costs. Technical, environmental and organizational conditions included incorrect and non-standard methods of implementation such as fly and fix that are common in metro workshops, lack of adequate personal protective equipment, electrical defects due to lack of proper installation and installation of equipment and absence of fall guard rails.

Table 1: Dimensions and Sub-dimensions of the safety unit budget and the combination importance with accident causes

Dimensions and Sub-dimensions	Point
1. Monitoring and control	4.54
a. Personnel Safety salary	4.27
b. Recruiting skilled Scaffolding	3.32
c. Recruit Traffic or Flight Controller man	3.42
d. Recruiting staff controlling	3.04
e. Periodic expert visit to outside of the metro project to identify hazards	3.32
2. Education	4.5
a. Principles of safety in the workplace	4.32
b. Emergency response and crisis maneuvering	3.73
c. Principles of fire extinguishing and maneuvering	3.91
d. Training courses for safety unit personnel	3.95
3. Buy Personal protection equipment	4.91
a. Helmets, safety shoes, work clothes, gloves, respiratory masks and safety handsets	4.69
b. Power insulation caps, safety shoes and electric clothing	4.27
c. Work hats in height, seat belts	4.27
4. Risk assessment of workshops	4.09
5. Buy portable extinguisher equipment	4.09
6. Construction of well	4.63
7. Buy Protective Keys	4.5
8. Buy safety signs	4
9. Warning system (Emergency alarms)	3
10. Emergency power supply	3.72
11. Action to obtain health certificates of machinery	4.45
12. Preparation of Workshop Safety Plan	3.04
13. Buy Safety engineering equipment (brake calipers and bulldozers)	3.04
14. Purchase of loading accessories	4.5
15. Buy flame back arrestors	3.86
16. Installation fall guard rails	4.86

The importance of the dimensions and percentage of the causes of the accidents were compared. The number of dimensions and sub-dimensions determined by the experts were the same as the causes of the accidents. However, the priority of the importance of spending the budget on the dimensions and sub-dimensions varied with the percentage of the direct costs of the causes of the accidents. The reason for this is quite logical and indicates the desirability of the results from this information because, despite the fact that spending sufficient funds on the performance of the safety unit is very effective, it alone is not enough to reduce workplace accidents. Functioning of the safety unit is primarily aimed at reducing workplace accidents, but other goals include

increasing staff productivity, increasing the atmosphere and safety culture in this regard. For better use of the information obtained in the proposed budgeting model, the combination of importance of each dimension and sub-dimension and the percentage of accidents was used.

2.3. The budgeting model of a metro station construction workshop

The proposed model was developed by using the information obtained in the previous stage and reviewing the documentation of the studied workshops and observations, as well as by interviewing the employed personnel and related to each dimension and distributors with the competence of safety equipment. This information included the cost of them and constrains of how they are spent according to the conditions, metro rules and regulations, as well as the standards and rules of safety for each dimension.

The model parameters included all the input information of a metro station construction workshop:

- n: Total number workshop
- n₁: The number of people who are temporarily added to the workshop within one year and have a maximum of 3 months.
- n₂: number of employees including technical unit engineers, implementation, mapping, oversight and personnel units, security and services
- n₃: unit number of units and facilities
- n₄: number of reinforcements
- n₅: digger number
- n₆: number of welder number
- s: total workshop area (m²)
- s₁: high-risk areas includes warehouses, Compressor and diesel fuel tanks generators
- s₂: medium-risk areas, including the conexas and the location of the workshop
- z: number of sub-workshops
- c: number of camps
- q: Number of Workshop Conexes
- m: number of Construction machinery
- h: number of access shafts
- r: the number of ramps
- w: number of wells (other than wells drilled for the pile)
- e: The number of power boards
- e₁: The number of power supply panels and workshops
- b: The number of cutting devices
- k: extinguishing factor (kg / m²)
- p_i: Importance of Dimensions
- R_i: percentage of accidents
- c_i: budget of dimension
- C: total budget of safet unit in one year

The decision variables of the model include the number of requirements for each of the dimensions and sub-dimensions.

$$X_i = X_1, X_2, \dots, X_{51}$$

Robust Linear Optimization Model Integrated Integer:

$$Max \sum_{i=1}^{51} (P_i + R_i) X_i$$

S.t.

$$\sum_{i=1}^{51} C_i X_i \leq C$$

$$X_i^{min} \leq X_i \leq X_i^{max}$$

$$i = 1, 2, \dots, 51$$

$$X_6 \leq n + n_1 - X_1 - 1$$

$$X_8 \leq 0/3 X_{26}$$

$$X_9 \leq 0/3 X_{27}$$

$$X_{10} \leq 0/1 X_{29}$$

$$X_{11} \leq 2 X_1 + 1$$

$$X_{22} \leq X_2 + \frac{n_4}{3}$$

$$X_{23} \leq X_2 + \frac{n_4}{3}$$

$$X_{24} \leq \frac{X_5}{2}$$

$$X_{32} \leq X_{25} + \frac{X_{26} + X_{27}}{2} + X_{29}$$

$$X_{33} \leq e + X_{30}$$

$$X_{36} \leq \frac{X_{50}}{25}$$

$$X_{46} \leq X_1$$

$$X_{47} \leq X_1$$

$$\text{If } X_1 = X_1^{max} \rightarrow Z_C = 0 \rightarrow Z_B = 0 \rightarrow X_3 \leq 2$$

$$X_3 \leq 3.5 \left(\frac{s}{25000} + \frac{m}{50} + \frac{n}{1000} + \frac{X_{30}}{10} + \frac{e}{50} + \frac{c}{5} \right)$$

$$\text{If } X_1 < X_1^{max} \rightarrow Z_C \neq 0 \rightarrow Z_B \neq 1 \rightarrow X_3 \leq M$$

$$X_3 \leq 5 \left(\frac{s}{25000} + \frac{m}{50} + \frac{n}{1000} + \frac{X_{30}}{10} + \frac{e}{50} + \frac{c}{5} \right)$$

$$X_3 \leq 3.5 \left(\frac{s}{25000} + \frac{m}{50} + \frac{n}{1000} + \frac{X_{30}}{10} + \frac{e}{50} + \frac{c}{5} \right) + M$$

$$X_1^{max} - X_1 = Z_C$$

$$\frac{Z_C}{M} \leq Z_B \leq M Z_C$$

$$X_3 \leq 2 + M Z_B$$

$$X_5 \leq 5 \left(\frac{s}{25000} + \frac{m}{50} + \frac{n}{1000} + \frac{X_{30}}{10} + \frac{e}{50} + \frac{c}{5} \right)$$

$$X_5 \leq 3.5 \left(\frac{s}{25000} + \frac{m}{50} + \frac{n}{1000} + \frac{X_{30}}{10} + \frac{e}{50} + \frac{c}{5} \right)$$

$$Z_C \geq 0$$

$$Z_B \in \{0,1\}$$

$$X_i \in \{1,2, \dots\}$$

In order to arrive at the model and solve it by Gurobi software version 7.01, the model was developed according to specific programming principles using the python software version 2.7.

3. Results and Discussion

The model presented in the previous section for the budgeting of the safety unit of one of the studied workshops, in which no information was used to construct the model, was implemented during 2016 (Figure 1). According to the requirements of the project for the construction of metro stations, 3% of the total workshops contract for HSE costs was considered, of which 1.7% was spent on safety costs.

Therefore, according to the total amount of contract and progress of activity in 2016, the predicted budget of the proposed model for the workshop was 7039.5 million rials. In order to determine how to choose the optimal number of each of the variables, the proposed model for the workshop under study was carried out with lower budget and higher budget than the actual budget of the workshop. Considering the structure of this model, which determined the number of optimal variables based on the importance of the cost, and taking into account the constraints, the validity of this function of the model was verified and tested by comparing and studying the causes and how to select the output of each variable with the different budgets of the decomposition. In this regard, the minimum amount of funding available for the proposed model was 4370 million rials (Figure 2). The budget spent in 2016 for the study workshop was calculated to be 4561 million rials. By comparing the amount spent on this workshop and the allowable amount of the projected budget, the difference of 2477 million rials represented the over-saving of the budget for the safety unit. In other words, the non-allocation of the necessary credits for the safety unit. Workshop. According to other surveys conducted and interviews with the personnel of the unit, it had a significant negative effect on the operation of the year 2016 in the workshop safety unit. The minimum amount of the budget required for the proposed model to be implemented in the workshop was slightly different from the budget spent in the workshop. Considering that project managers and supervisors of workshops are always willing to reduce their costs due to the conditions and limitations of funding, development projects are always willing to reduce their costs and, as much as possible, save resources in non-executive and operational units such as safety units. It should inevitably come to fruition; this disparity in the budget represents the correct performance of the model.

	A	B	C	D	E	F	G	H	I	J	K
1	Resource	LB	x*	UB	L/U/Mid	avg_cost	avg_p	avg_p/avg_cost			
2	1	3	4	5	Mid	28/2	98/052095	3/47			
3	2	2	2	2	U	25/2	95/973985	3/8			
4	3	1	3	3	U	18/1	78/234883	4/32			
5	4	2	4	4	U	21/6	69/892344	3/23			
6	5	4	8	10	Mid	0/4	76/146733	190/36			
7	6	195	322	326	Mid	0/0325	95/505686	2938/63			
8	7	1	1	1	U	0/275	82/444171	299/79			
9	8	2	3	3	U	0/053	86/459253	1631/3			
10	9	1	2	2	U	0/018	86/459253	4803/29			
11	10	1	1	4	L	0/0195	86/459253	4433/8			
12	11	7	9	11	Mid	0/042	87/466432	2082/53			
13	12	366	616	616	U	0/01425	95/011347	6667/46			
14	13	366	616	616	U	0/0675	95/014983	1407/62			
15	14	243	661	661	U	0/06	98/014983	1633/58			
16	15	2970	5598	5598	U	0/0085	95/014983	11178/23			
17	16	3486	6118	6118	U	0/016	95/014983	5938/43			
18	17	26	45	45	U	0/025	95/014983	3800/59			
19	18	25	45	45	U	0/0325	95/014983	2923/53			
20	19	18	18	18	U	0/01175	86/704839	7379/13			
21	20	18	18	18	U	0/073	86/704839	1187/73			
22	21	18	18	18	U	0/075	86/704839	1156/06			
23	22	14	18	19	Mid	0/05	86/709384	1734/18			
24	23	14	18	19	Mid	0/325	86/704839	266/78			
25	24	2	4	5	Mid	0/6	87/795295	146/32			
26	25	2	3	3/84	Mid	0/1925	81/818182	425/02			
27	26	12	20	20	U	0/0885	81/82	924/51			
28	27	6	7	7/34	Mid	0/0815	81/82	1003/92			
29	28	12	22	22	U	0/0465	81/82	1759/56			
30	29	7	15	15	U	0/128	81/82	639/21			
31	30	2	2	2/62	L	3/75	92/727273	24/72			
32	31	56	91	91	U	0/0675	91/753938	1359/31			
33	32	18	31	33	Mid	0/00775	80	10322/58			
34	33	9	17	17	U	0/00275	80	29090/9			
35	34	6	8	8	U	0/0145	80	5517/24			
36	35	8	16	16	U	0/0115	80	6956/52			
37	36	20	22	23	Mid	0/0115	80	6956/52			
38	37	3	7	7	U	0/0145	80	5517/24			
39	38	2	4	4	U	0/0115	80	6956/52			
40	39	8	11	11	U	0/02	80	4000			
41	40	10	18	18	U	0/0475	80	1684/21			
42	41	1	2	2/28	Mid	0/35	60	171/42			
43	42	1	1	1	U	51	74/545455	1/46			
44	43	14	22	22	U	0/475	89/090909	187/55			
45	44	1	1	1	U	0/85	60/909091	71/65			
46	45	1	1	1	U	0/125	60/909091	487/27			
47	46	3	4	5	Mid	0/011	60/91	5537/27			
48	47	3	4	5	Mid	0/0625	60/91	974/56			
49	48	2	4	4	U	2	90	45			
50	49	12	24	24	U	0/05	77/272727	1545/45			
51	50	508	556	556	U	0/0295	98/199337	3328/79			
52	51	15	27	27	U	0/0452	93/196609	2061/87			

Figure 1: The output of the model with a 7039.5 million rials budget

	A	B	C	D	E	F	G	H	I	J	K
1	Resource	LB	x*	UB	L/U/Mid	avg_cost	avg_p	avg_p/avg_cost			
2	1	3	3	5	L	28/2	98/052095	3/47			
3	2	2	2	2	U	25/2	95/973965	3/8			
4	3	1	1	3	L	18/1	78/234863	4/32			
5	4	2	2	4	L	21/6	69/892344	3/23			
6	5	4	4	10	L	0/4	78/146733	190/36			
7	6	195	195	326	L	0/0325	95/505686	2938/63			
8	7	1	1	1	U	0/275	82/444171	299/79			
9	8	2	2	3	L	0/053	88/459253	1631/3			
10	9	1	1	2	L	0/018	86/459253	4803/29			
11	10	1	1	4	L	0/0195	86/459253	4433/8			
12	11	7	7	11	L	0/042	87/466432	2082/53			
13	12	366	366	616	L	0/01425	95/011347	6667/46			
14	13	366	366	616	L	0/0675	95/014983	1407/62			
15	14	243	243	661	L	0/06	98/014983	1633/58			
16	15	2970	2970	5598	L	0/0085	95/014983	11178/23			
17	16	3486	3486	6118	L	0/016	95/014983	6938/43			
18	17	26	26	45	L	0/025	95/014983	3800/59			
19	18	25	25	45	L	0/0325	95/014983	2923/63			
20	19	18	18	18	U	0/01175	86/704839	7379/13			
21	20	18	18	18	U	0/073	86/704839	1187/73			
22	21	18	18	18	U	0/075	86/704839	1156/06			
23	22	14	14	19	L	0/05	86/709384	1734/18			
24	23	14	14	19	L	0/325	86/704839	266/78			
25	24	2	2	5	L	0/6	87/795295	146/32			
26	25	2	2	3/84	L	0/1925	81/818182	425/02			
27	26	12	12	20	L	0/0885	81/82	924/51			
28	27	6	6	7/34	L	0/0815	81/82	1003/92			
29	28	12	12	22	L	0/0465	81/82	1759/66			
30	29	7	10	15	Mid	0/128	81/82	639/21			
31	30	2	2	2/62	L	3/75	92/727273	24/72			
32	31	56	56	91	L	0/0675	91/753938	1359/31			
33	32	18	18	33	L	0/00775	80	10322/58			
34	33	9	9	17	L	0/00275	80	29090/9			
35	34	6	6	8	L	0/0145	80	5517/24			
36	35	8	8	16	L	0/0115	80	6956/52			
37	36	20	20	23	L	0/0115	80	6956/52			
38	37	3	3	7	L	0/0145	80	5517/24			
39	38	2	2	4	L	0/0115	80	6956/52			
40	39	8	8	11	L	0/02	80	4000			
41	40	10	10	18	L	0/0475	80	1884/21			
42	41	1	1	2/28	L	0/35	60	171/42			
43	42	1	1	1	U	51	74/645455	1/46			
44	43	14	14	22	L	0/475	89/090909	187/55			
45	44	1	1	1	U	0/85	60/909091	71/65			
46	45	1	1	1	U	0/125	60/909091	487/27			
47	46	3	3	5	L	0/011	60/91	5537/27			
48	47	3	3	5	L	0/0625	60/91	974/56			
49	48	2	2	4	L	2	90	45			
50	49	12	12	24	L	0/05	77/272727	1545/45			
51	50	508	508	556	L	0/0295	98/199337	3328/79			
52	51	15	15	27	L	0/0452	93/196609	2061/87			

Figure 2: The output of the model with a 4370 million rials budget

4. Conclusion

Lack of financial resources for development projects is one of the main concerns of project managers and supervisors of workshops. However, unfortunately, due to lack of sufficient studies and traditional budgeting, we still encounter significant financial resources in projects. The safety unit,

which has been recently added to metro projects in Iran, is observed by some managers as a low priority unit and should only be the first response after the incident. According to the study of the conditions of the other metro construction workshops, the least attention and allocation of funds to prevent the accidents are not sufficient. The essence of safety issues is to prevent accidents and not to spend multiple times

on the cost of accident compensation. On the other hand, most project managers attempt to cut costs and spend on tangible or timely issues, thereby avoiding expenses on safety issues as much as possible. This model was based on the detailed study of the situation, a significant number of subway workshops, expert interviews designed to determine the relationships between each of the dimensions and the use of existing rules and standards achieved by entering certainly or uncertainly information for other metro workshops.

Limitation

The rules and standards of the metro project are more in line with the safety requirements, and in order to use the rules and standards to identify the relationships between the parameters and variables, it is necessary to use the specific rules of each of the dimensions. The quality of the information gathered to construct the model had a significant impact on the structure of the model and the logic of the results. Therefore, it takes much time to collect the necessary information, including input parameters of the model, costs, importance of the relationship and the dimensions. Due to the large amount of information needed to build this model, the requested community had a good database and the researcher had full access to the database. One useful way to reduce this problem and justify project managers is to make safety managers aware of the economic and cost aspects, while taking into account the limited resources of the organization, can accurately predict the cost of their safety unit for future time. Moreover, by appropriate economic justification, while changing the culture of project managers, they are required to spend the necessary funds to advance the goals of this unit.

Authors' Contributions

S.M.F., gathered the data and wrote the manuscript; Sh.A., designed the study and wrote the manuscript; Sh.A., analyzed the data; and F.M., designed the study. All the authors revised the final manuscript.

Conflict of Interest

The author report no conflict of interest.

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