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Factors Affecting on Productivity of Oil and Gas Construction Projects: An AHP Analysis

Khalegh Barati[1,*], Samad M.E. Sepasgozar[2,*]

[1]Sharif University of Technology, Tehran, Iran
[2]Tarbiat Modares University, Tehran, Iran
*Corresponding author: khalegh.barati@yahoo.com; samad.sepasgozar@gmail.com

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Abstract The oil and gas construction sector is one of the main industries all over the world which plays a powerful role in economic growth of all countries inasmuch as accounts 5 to 10 percent of Gross national product (GNP) of countries. Over the last decade, by considering the huge amount of money spent in constructing these kinds of mega projects, the issue of identifying affecting factors and their roles on productivity has become main challenge for engaging teams in the process of execution. In spite of its importance, no extensive and comprehensive researches have been yet conducted to assess the effective factors in productivity of these projects. This paper presents several factors affecting the productivity in the oil and gas construction projects. The paper also provides a priority list of important factors affecting the productivity based on a survey conducted in a large oil zone. Respondents involved in employer organizations, construction managers and consultants, contractor teams and university lecturers. Finally, through Analytical Hierarchical Process (AHP) and paired comparison between the effective factors and categorized groups, the importance and the effect of these factors on productivity of oil and gas construction projects were obtained. The result of the analysis shows that management factors are most effective factors while project's factors do not have significant effect on productivity.

Keywords: *productivity, oil and gas construction projects, paired comparison, importance index, severity index, Analytical Hierarchical Process (AHP)*

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1. Introduction

The issues concerning in determination of the factors affecting on productivity and their importance have been recently focused by many researchers and as a result, the effects of these factors on construction industry have been determined. Different factors have been investigated in this regard including factors related to the management [1,2,3], factors related to construction methods and weather conditions [2], issues related to working hours and shifts [4] as well as topics related to labor characteristics [5].

Nonetheless, these investigations have been separately concentrated on assessing productivity of activities and tasks of jobs, while productivity at different levels such as national level, industry level, company level and project level may be considered. However, it is worthy to note that assessment of productivity at the level of the activities of jobs cannot be applied for assessment of productivity at the level of a project, because there is missing in linkages between the activity factors. Furthermore, the results of a seven-year research done in the United of States [6] shows that many of these factors which have been identified and assessed are incomplete and sometimes contradictive. Therefore, these factors cannot describe the facts in relation to productivity in detail. Besides that, there is no regular data collection and no regular measurement of productivity, either by industry or by government. Therefore, it can be asserted that despite extensive researches conducted in this regard, there are still many unknown factors affecting on productivity that require a comprehensive and integrated research in this issue. Also, by reviewing the recent studies as well as the results of the research conducted by Haskell, it is clear that the factors affecting on productivity are not absolutely and necessarily independent factors. Furthermore, these factors have been considered by different researches who have had different points of view and consequently, results has been different and even contradictive in some occasions.

Because of this, it is necessary that a comprehensive and complete illustration of different aspects of such projects to be provided for better understanding the factors affecting on productivity and then by investigation of every aspect, the factors affecting on productivity determined and assessed, accordingly. Through depicting a comprehensive illustration of oil and gas construction projects, the present research intends to develop a model to identify and categorize the factors affecting on productivity. After that, through applying Analytical Hierarchical Process (AHP) and paired comparison,

importance, frequency and severity indices of effective factors on productivity were calculated. This study has examined the determinants of productivity at project level [7,8].

2. Productivity in Oil and Gas Projects

Because of so many engaging teams in the execution phase of oil and gas construction projects such as civil, electrical, mechanical and quality control (QC) teams, these projects are most complicated construction project. In spite of huge expenses spent for execution of oil and gas projects as well as the vitality of such projects for the economy of the countries, a few researches have been conducted on productivity of such projects. Jergeas defined these projects as being huge in magnitude and over $1 billion in total installed cost, excluding development costs expended prior to the project being formally approved. These projects are characterized by a significant number of interfaces, interdependencies, complexity, and risks, some of which are strategic and must be managed at a level above the project team.

According to a research conducted by Jergeas, cost, extra time and workforce factors are among the important issues affecting on productivity of such projects which are the direct result of the management team weakness. Generally, these projects are successful at engineering, safety and operational levels. Also, Fayek [10] concluded that due to the relative similarity of the projects in this industry, employing the data and experiences of the previous projects may enhance productivity of subsequent projects drastically. Furthermore, in his research, Lozon [11] found that limited budget and contractual strategy as the most important factors affecting on productivity of oil and gas projects. In addition, CRCPM has suggested a useful source for identification of the factors affecting on productivity of such mega projects [12].

3. Factors Affecting on Productivity of Oil and Gas Construction Projects

Factors affecting productivity are presented in the literature. However, key specific influential factors affecting the productivity of mega oil and gas construction projects have been ignored. In addition, the importance of previous factors in oil projects is remained questionable. The most important part of this paper was having a comprehensive and all-out research for identifying different affecting factor on productivity of oil and gas construction projects. Based on conducted research, these factors are varied from workforce and management to weather conditions and personal health. It is worthy to mention that many investigations have been conducted in this regard in recent years. However, despite of these studies, no general consensus was reached regarding identification of the factors significantly affecting on productivity as well as categorization of such factors. Consequently, these factors have been identified and categorized based on own viewpoint of an individual researcher and finally has led to providing different models in this regard [9,13].

Taking into account of preceding studies, in the present paper a comprehensive and all-out model is suggested for identification and categorization of the factors affecting on productivity. At first, five main previous researches in this area implied in the following were reviewed in this regard. Then, after deletion, modification and integration of the similarities, the results obtained were categorized under different categories and the views of the experts involved in this industry concerning these factors and their categorization criteria were collected. Finally, 63 factors affecting on productivity were identified and categorized under 5 categories.

1. Studies conducted by CRCPM: 10 factors affecting on productivity were identified [12].
2. Research conducted by Soekiman: 113 factors affecting on productivity were identified and categorized under 15 categories [5].
3. Research conducted by CURT and CCIS Institutes and CAA: factors affecting on productivity were identified [8].
4. Studies conducted by Hwage: 51 factors affecting on productivity were identified and categorized under 9 categories [14].
5. Research conducted by Alinaitwe: 40 factors affecting on productivity were identified and categorized under 4 categories [15].

4. Analytic Hierarchy Process (AHP)

AHP is one of the most applicable multi criteria decision making techniques which was developed by al-saaty in 1980. It has wide application in fields such as management, business, industry, engineering and education. AHP helps decision makers to find one alternative that best suits their goal and their understanding of the alternatives and criteria. It provides a comprehensive and rational framework for structuring a decision process. Users of the AHP first decompose their decision into a hierarchy which is known as decision tree. The elements of the hierarchy can relate to different aspect of the decision. Once the hierarchy is built, the decision makers systematically evaluate its different elements by comparing them to one another two at a time, with respect to their impact on an element above them in the hierarchy. The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the decision. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the AHP from other decision making techniques. In the final step of the process, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative point to achieve the decision goal.

5. Research Methodology

Research-based questionnaires and interviews with the concerned experts have been used as a tool for data gathering in this study. The main part of data obtained is based on the views and inferences of the respondents and

it is expected that these results are based on the working experiences of the participants. Totally, the numbers of 94 questionnaires were distributed among employer team, contractor team, consultation bureau, plans management and university researchers, 63 of which were returned after completion. By ignoring the defective ones, the numbers of 49 questionnaires were considered. Also, 8 interviews were conducted with the experts involved in this industry and their views were collected and applied in the results.

Work experiences as well as the positions of the respondents and interviewees are given at Table 1 and 2, respectively. The average of work experiences of the respondents and interviewees in oil and gas construction projects has been 9 years. As far as possible, it has been intended that the respondents and interviewees to be selected from all sectors involved at the project including management, supervision, execution and design teams.

Table 1. Respondents' work experience in Oil and Gas construction projects

Related work experience	%
2-6	33
6-10	29
10-15	18
15-20	8
>20	12

Table 2. Respondents' Positions

Position	%
Project Manager and Controller	18
Supervisor and Inspector	13
Estimator and Surveyor	15
Foreman	8
Management Contractor	19
University Lecturer	13
Others	25

The questionnaires were designed so that these factors have been considered qualitative by the respondents. First of all, their impacts were categorized under 5 categories as follows: very low impact, low impact, medium impact, high impact and very high impact. According to AHP structure and paired comparisons, the experience has proved that 9-paired comparison has been logical and it can reflect the difference of factors' impact severity so that a difference can be distinguished between the severities of factors' relationship [16,17]. After collection of questionnaire results, the qualitative scale was translated into numerical values (1= very low impact, 3= low impact, 5= medium impact, 7= high impact and 9= very high impact). At the second part of the questionnaire, the respondents were required to repeat their views qualitatively concerning the frequency severity of these factors affecting on productivity as low frequency severity, medium frequency severity and high frequency severity and then these results were converted into numerical values (1= low frequency severity, 3= medium frequency severity and 5= high frequency severity). Finally, the quantitative data were analyzed using the following formulas and Importance index, Frequency Index and Severity Index were obtained, accordingly [16,18].

$$\text{Importance index} = \frac{9n_5 + 7n_4 + 5n_3 + 3n_2 + n_1}{n_1 + n_2 + n_3 + n_4 + n_5}$$

$$\text{Frequency index} = \frac{5m_3 + 3m_2 + m_1}{(m_1 + m_2 + m_3)}$$

$$\text{Severity Index} = \text{Importance Index} * \text{Frequency Index}$$

Where, n_1, n_2, n_3, n_4 and n_5 stand for the numbers of responds given for very low impact, low impact, medium impact, high impact and very high impact for each individual factor. In addition, m_1, m_2 and m_3 stand for the numbers of responds given for low frequency severity, medium frequency severity and high frequency severity for each individual factor.

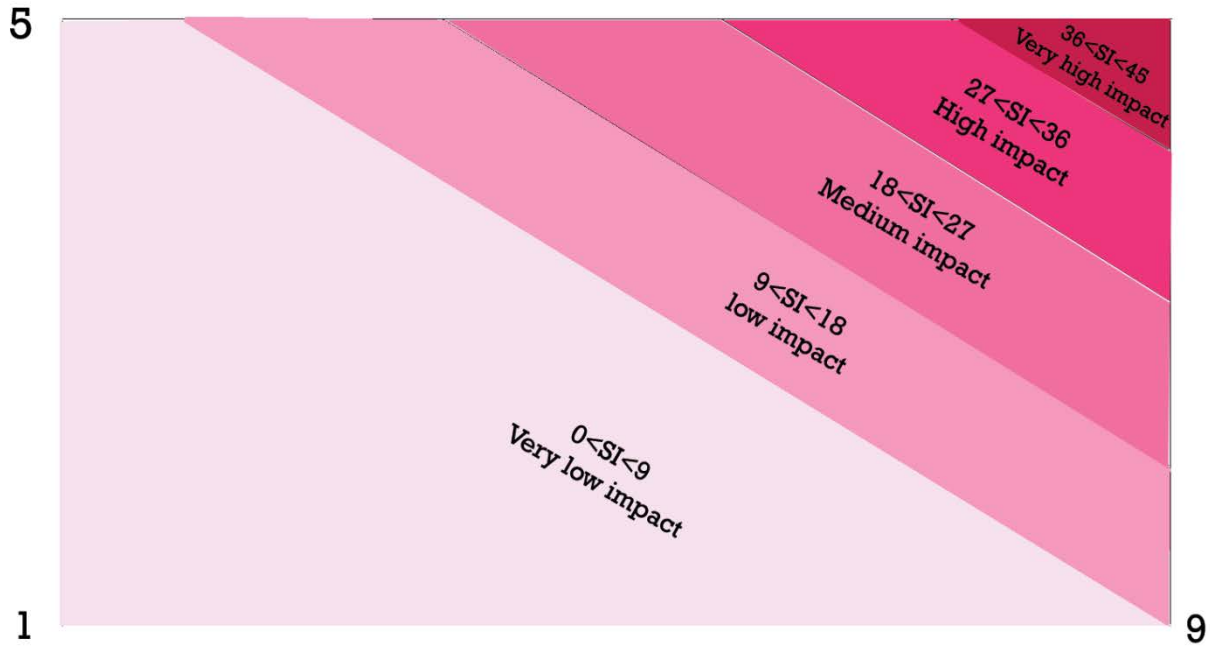

Figure 1. Assessment of the effects different factors have on productivity

After calculation of severity index, the factors affecting on productivity of oil and gas construction projects were categorized under 5 categories in accordance with their severities indices as well as drawing contours and they may be simply investigated and assessed by the managers. Then, by calculating severity index for each factor, total and relative importance indices of the factors affecting on the productivity at different levels were obtained. In fact, these factors were compared with each other according to paired comparison method. Sequence of mathematical calculations used for AHP is an effective method to obtain total and relative importance indices.

Since AHP method is based on paired comparison, first of all paired comparison matrix ($w=a_{ij}$) is obtained which is a matrix of (n*n) type. ("n" refers to the number of indices considered for paired comparison matrix). The elements of this matrix show the elements' weight ratio of i and j. ($a_{ij} = SL_i/SL_j$). Paired comparisons between the factors affecting on productivity are defined for better understanding and simpler comparison of a paired criteria at a given time in relation to the relative importance attributed to the criteria within general set of factors. For calculation of relative importance indices, a paired comparison matrix is developed for different levels of AHP. Then the rows of these matrices are added to the extent that a column vector is obtained. Finally, the vector obtained is normalized. This normalized vector is called eigenvector which shows the relative importance index at different levels. [16]

$$\begin{bmatrix} R_{11} & \cdots & R_{j1} & \cdots & R_{1n} \\ \vdots & \ddots & \vdots & \vdots & \vdots \\ R_{i1} & \cdots & R_{ij} & \cdots & R_{in} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ R_{n1} & \cdots & R_{jn} & \cdots & R_{nn} \end{bmatrix} \Rightarrow \begin{bmatrix} C_1 \\ \vdots \\ C_i \\ \vdots \\ C_n \end{bmatrix}$$

W C

As indicated above, C and W stand for eigenvector and paired comparison matrix. Also,

$$R_{ij} \times R_{ji} = 1 \quad R_{ii} = 1 \; i,j = 1,2,\ldots,n$$

6. Reliability and Validity of Questionnaires Results

Pragmatic control of the results of questionnaires and interviews includes a wide range of different issues which the reliability of the data and validity of the questionnaires are the most important them [17]. Validity refers to the capability of the questionnaire to gather the data for which it has been designed [18]. To enhance the validity, the following items were applied at the questionnaires and interviews:

1. Investigation into and frequent edition of the questionnaires and interviews based on the experts' views.
2. Justification of the respondents.
3. Maintaining congruity and homogeneity of the respondents.
4. Clarification of the ambiguities of the questionnaires.

In addition, for calculation of the reliability of the results of the questionnaires, the results were introduced at Likert scales at SPSS Statistical Software [18]. By calculation of Cronbach's Alpha, importance index of 0.85 and frequency index of 0.88 were obtained, respectively which indicate very good results for reliability of data in the scale of Likert.

7. Results Analysis

In the present research, through having comprehensive review on previous researches and interviewing with specialists in this field, 63 factors affecting on productivity of oil and gas construction projects were identified and considered. After that, these factors were categorized into five categories as project's factors (8 factors), external factors (9 factors), organizational factors (17 factors), labor factors (10 factors) and management factors (19 factors). Then, by quantification of the results of the questionnaires and interviews as well as employing the formulas as described above, importance, frequency and severity indices were obtained. Finally, by conducting AHP and Paired Comparison, total and relative importance indices of the factors affecting on productivity were calculated and the impacting rate of these factors was established.

7.1. Project's Factors

Factors involved at characteristics of project and the effects they have on productivity of oil and gas projects are given at Table 3. As found by the results given at this table, these factors do not have significant effects on productivity. The most important factors classified under this category are the complexity of project, risk level of project.

Table 3. Ranking factors related to characteristics of project affecting on productivity

Project's factor	II	FI	SI	RII	TII	RANK
Complexity	5.6	2.3	12.88	12.676	1.133	46
Modernity	4.1	1.8	7.38	7.2632	0.649	62
Size and Dimensions	5.1	2.8	14.28	14.054	1.256	40
Location and Accessibility	3.4	3.3	11.22	11.042	0.987	51
Repeatability of project's elements	4.6	2.9	13.34	13.129	1.173	43
Working congestion and limited working space	5.85	2.05	11.99	11.803	1.055	47
Project's risk level	5.9	3.4	20.06	19.743	1.764	22
Requiring new technology	4.1	2.55	10.455	10.29	0.919	53

7.2. External Factors

Analysis results of the questionnaires regarding 9 factors affecting on productivity of oil and gas projects are given at Table 4. Generally speaking, these factors do not

have significant effect on productivity and their frequencies severities during execution of the projects are low. The most important of these factors is climatic conditions with severity index of 18.76 and 12th rank.

Table 4. Ranking external factors affecting on productivity

External factors	II	FI	SI	RII	TII	RANK
Modification of governing laws	5.8	2.5	14.5	11.126	1.275	38
Land conditions	4.1	2.05	8.405	6.4495	0.739	60
Security	6.1	2.8	17.08	13.106	1.502	32
Climatic conditions	7.3	3.35	24.45	18.765	2.151	12
Disputes settlement systems	4.2	2.25	9.45	7.2514	0.831	57
Delay in equipment arrival	6.9	3.4	23.46	18.002	2.063	14
Executive measures and byelaws	2.9	3.4	9.86	7.566	0.867	54
Inflation, stagnation and non-stability of prices	3.95	2.4	9.48	7.2744	0.834	56
Political conditions	5.8	2.35	13.63	10.459	1.199	42

7.3. Organizational Factors

Organizational conditions of project as factors affecting on productivity and importance, frequency and severity indices as well as their ranking among all affecting factors are given at Table 5. Terms of payment, liquidity flow of project having score of severity index of 35.235 are among the most important organizational factors affecting on productivity of oil and gas construction projects. In addition, redoing and modifications applied at designs and specifications and budget appropriated to project having score of s indices of 32.39 and 29.23 are placed at subsequent ranks. These results confirm the research conducted by Jergeas [9] and Lozon [11] on productivity of oil and gas construction projects in Alberta County of Canada.

Table 5. Ranking organizational factors affecting on productivity

Organizational factors	II	FI	SI	RII	TII	RANK
Contractual strategy	6.95	2.9	20.15	6.0677	1.722	20
Project organizational chart	5.4	2	10.8	3.2514	0.95	52
Expedition of execution of project	4.9	2.9	14.21	4.278	1.25	41
Involved organizations execution rules	4.25	2.15	9.13	2.7509	0.804	58
Contractors numbers and work breakdown level	7.4	3.2	23.68	7.1289	2.082	13
Clarification of works delegation	5.6	2.55	14.28	4.299	1.256	39
Coordination level of involved teams	5.4	2.8	15.12	4.5519	1.33	37
Interconnection level among involved groups	5.2	2.2	11.44	3.444	1.006	50
Claims and disputes effects	5.95	3.8	22.61	6.8068	1.988	15
Payment terms and liquidity flow	8.1	4.35	35.23	10.608	3.099	3
Appropriated budget	7.9	3.7	29.23	8.7998	2.571	7
Contracts administration	5.4	2.8	15.12	4.5519	1.33	36
As-built drawings and designs clarification	6.6	2.75	18.15	5.4641	1.596	28
Project definability Level at awarding time	6.5	2.6	16.9	5.0878	1.486	33
Redoing and design modification	7.9	4.1	32.39	9.7511	2.848	5
Salary and fringe benefits systems	7.2	3.1	22.32	6.7195	1.963	16

7.4. Labour Factors

Rating 10 factors related to labour affecting on productivity of oil and gas construction projects is given at Table 6. Generally speaking, these factors have had medium effect on productivity with medium frequency index. Among these factors, proficiency and experience related to the career (profession) with severity index of 26.47 has been placed at the first rank among the indices and 9th rank among all indices identified. By reviewing the table, it can be concluded that absence and delays of workforce and morale and sense of team working are placed at subsequent ranks.

Table 6. Ranking labour factors affecting on productivity

Labour factors	II	FI	SI	RII	TII	RANK
Labours absence and delays	6.9	3.9	25.91	15.895	2.367	10
Experience of environmental conditions	4.2	2.1	8.82	5.2096	0.776	59
Boredom and illness	6.4	2.95	18.88	11.152	1.66	26
Career- related proficiency and experience	7.9	3.35	26.47	15.632	2.327	9
Expectations and job satisfaction	6.25	2.9	18.13	10.706	1.594	29
Cultural and social restrictions	3.65	2.05	7.483	4.4196	0.658	61
Level of graduation	5.35	2.2	11.77	6.9521	1.035	49
Morale and sense of team working	6.9	4.05	27.95	16.506	2.458	11
Age and gender of labour	4.5	2.15	9.675	5.7146	0.851	55
Learning curve of labour	4.9	2.7	13.23	7.8144	1.163	45

7.5. Management Factors

Almost, all managerial factors have had significant effect on productivity of oil and gas construction projects which have been classified in terms of importance in Table 7. Budgeting and costs management with severity index of 36.81 achieved the first rank of the factors affecting on productivity of these mega projects. Timing and planning the resources, goods and equipment chain management and employing data and experience of previous projects having score of severity indices of 36.23, 34.4 and 30.03 have achieved the subsequent places. It is worthy to note Jergeas has achieved the same results in his own research.

Table 7. Ranking management factors affecting on productivity

Management factors	II	FI	SI	RII	TII	RANK
Motivation and incentive plans	7.2	3.9	28.08	6.9557	2.469	8
HSE management	5.4	3.7	19.98	4.9492	1.757	23
Quality system management	5.4	3.6	19.44	4.8155	1.71	25
previous projects experience employing	7.8	3.85	30.03	7.4387	2.641	6
Inventory controlling and warehousing	5.9	2.9	17.11	4.2383	1.505	31
Project information management	5.9	3.1	18.29	4.5306	1.608	27
Timing and planning resources	8.05	4.5	36.23	8.9732	3.186	2
Inadequate supervision and inspection	6.1	3.4	20.74	5.1375	1.824	18
site layout	5.2	2.55	13.26	3.2846	1.166	44
supplying chain management	8	4.3	34.4	8.5212	3.025	4
Project's risk management	6.2	3.25	20.15	4.9913	1.772	21
Labour change and substitution	5.8	3.55	20.59	5.1003	1.811	19
Equipment maintenance management	4.2	2.85	11.97	2.9651	1.053	48
Welfare facilities at sites and camps	5.9	3.05	18	4.4557	1.583	30
Labour training	5.95	2.8	16.66	4.1268	1.465	34
Cleaning of site	3.35	1.9	6.365	1.5767	0.56	63
Managers/personnel Collaboration level	5.6	3.55	19.88	4.9244	1.748	24
Planning of shifts and working hours	6.4	2.45	15.68	3.8841	1.379	35
Budgeting and costs management	8.1	4.55	36.86	9.1293	3.241	1

As found taking into consideration of above tables and the following chart, management factors having score of 36% has achieved the first rank at oil and gas projects which indicates the important role the management plays in mega projects. Furthermore, Jergeas during conducting his own research on productivity of oil projects in Alberta has reached the same results. Organizational factors having score of 29% achieved the second rank. Factors related to project's factor (9%) as well as external factors (11%) proved their relatively low effect on productivity of such projects. By reviewing the similar construction projects, it is found that these factors have lower effect on productivity of oil and gas projects than other civil projects.

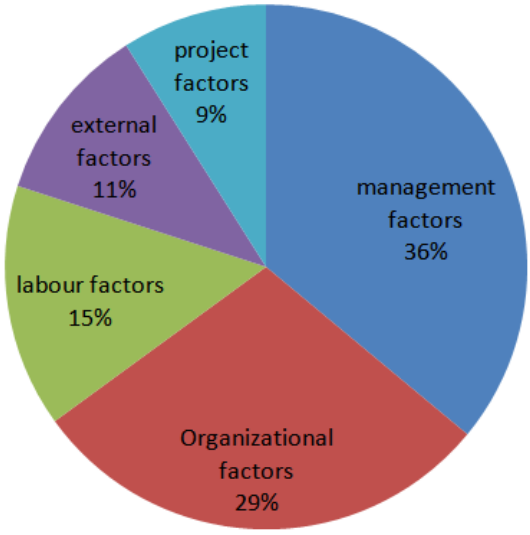

Figure 2. comparing the role different factors on productivity

8. Discussion and Conclusion

In the present article, the factors affecting on productivity of oil and gas project were identified and the degree of their impact was obtained. At first, by reviewing the preceding studies conducted in this regard as well as opinion polling, the effective factors were identified and categorized and then through distribution of questionnaires and successive interviews, the opinions of the concerned experts were collected and by employing the respective formulas, importance index, frequency index and severity index were obtained. Thereafter, by conducting AHP and paired comparison of these factors, the indices of relative and total importance were obtained and finally, these factors were classified in terms of their effect on productivity of mega projects. Furthermore, these factors were categorized under five categories in terms of severity index which is influenced by importance and frequency indices.

Generally speaking, managerial-related factors have achieved higher scores of productivity of oil and gas projects which signify the important role these factors and management teams play in these projects. Among them, budgeting and costs management, timing and planning resources and goods supplying chain management are the most important ones. Also, given the huge financial sources required for construction of these projects, factors related to budget and financial issues play a vital role in productivity of these projects. Generally, it can say that these projects are successful ones in terms of engineering, safety and information management factors. On the other hand, external factors and characteristics of project have a relatively low effect on productivity of such projects.

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