

Research Trends on Benefits of Implementing Constructability, Operability, and Maintainability

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Abstract: Despite allocating huge budgets to civil engineering projects, detailed planning, and employing human resources, project managers still face time, cost, and quality constraints. Most of these challenges are due to a lack of integration of different project phases and the limitations of the presence of construction and maintenance contractors in the initial stages of the project. Considering the benefits of applying constructability, operability, and maintainability (COM) concepts, many problems caused by lack of coordination, or duplications and weakness in management, and also time and extra costs due to lack of presence of construction and maintenance contractors in the early stages of the project are resolvable. In this regard, various studies have investigated the benefits of applying these concepts; however, there has been no comprehensive analysis of the benefits of COM. As a result of focus on the benefits of implementation of these concepts and evaluating the effect of each of these strategies and benefits, from different perspectives during various time periods, managers can increase project efficiency and productivity, and improve their performance, through using concepts and strategies of their implementation. This research aims to evaluate the trend of studies on the benefits of implementing constructability, operability, and maintainability in the construction industry. For that, the in-depth literature review method is applied. For qualitative analysis of the obtained information, descriptive analysis has been used. Then, the data was coded, and classified using Excel Software for quantitative data analysis. Finally, the charts presented were evaluated according to the classified fields of study. The necessity of performing such a study is significant because of the fact that a large share of a project's problems, such as lack of plans' integration and weakness of administrative system, and increasing time and cost, are due to lack of exchange of information and ineffective relationship between the design people and the construction and maintenance stakeholders, and ignoring the effects of design decisions on constructability and operability and maintainability implementation.

Keywords: Evaluation trend, constructability, operability, maintainability, integration, construction projects.

1. Introduction

Nowadays, lack of integration of the design, construction and maintenance stakeholders in construction projects are among the biggest problems in this field. This separation leads projects not to achieve real success (Yustisia, 2014). In order to align the project objectives and to coordinate changes, it is necessary to run constructability and operability and maintainability programs. Systemic constructability is to achieve optimal integration from construction knowledge and experience in the earlier stages of the project life cycle. It creates balance in different projects and supplies environmental frameworks to achieve the overall objectives of the project efficiently (Yustisia, 2014). Operability is also defined as ease of operation (Incorporated, 1996). It is operational capability

of a system that performs its expected activities Trigunarsyah (2010). Trigunarsyah and Skitmore (2010) define maintainability as the ability to retain or ease of maintenance. The necessity of the presence of construction and maintenance contractors in the early stages including the design phase, arises from this fact that a lot of project's problems, including duplications, increasing time and costs, lack of integration of plans, and weakness of administrative systems, are because of lack of a proper information exchange and effective relationship building in the design and construction phases.

The above concepts lead to improved performance and significant savings in all dimensions of a project, such as time and cost, during its process from beginning

to its operation and maintenance stages. These benefits are provided through developing fields to facilitate the presence of chief contractors in the early phases of the project. This is a long term issue, and should be followed continuously. Before beginning the construction, facilitating the proper implementation of these concepts should be targeted (Yustisia, 2014). By now, there is no comprehensive study evaluating the trend of studies on the benefits of Constructability, Operability and Maintainability (COM) principles' implementation in the construction industry. Such studies lead to transparency. Moreover, there is no official statistical report in this regard. Most of these studies have been about introducing (CIIA, 1993; IPENZ, 2008; Russell, nd), identifying the barriers to and solutions of implementing these concepts (Francis et al., 1999; Jadidoleslami et al., 2015; JadidolEslami et al., 2016; Meier et al., 2000; O'Connor et al., 1995; O'Connor et al., 1988; O'Connor et al., 1994; Kordestani, 2016). In addition, understanding the relationship and applying other science to realize these principles (Amirarjmandi et al., 2011; Francis, V. E. et al., 1996; Hui-Hsuan et al., 2013; Jadidoleslami, Samereh et al., 2016) have also been the focus of the conducted studies in this field. The aim of this study is evaluating the trend of studies about implementing constructability, operability, and maintainability principles in the construction industry.

2. Constructability, Operability, and Maintainability

Cost due to duplications is one of the most obvious challenges of construction time for project employers, which leads to deviation from the predicted time and budget of the project. These problems stem from isolation and lack of proper integration in the project phases (Francis and Sidwell, 1996). In fact, constructability refers to using knowledge and experience together to optimize construction in all stages of planning, designing, logistics, and implementation (Yustisia, 2014). Constructability was introduced in USA in 1970s. These studies were mainly about management and participation systems of employers and contractors. In 1979, the faculty of research institute of the construction industry suggested research about identifying the problems related to operability/constructability in the USA construction industry. These researches showed that constructability problems are caused by lack of contribution of planners and designers in implementation processes of construction, not shortcomings and negligence by staff (CIRIA, 1983).

Operability is described as ease of operation (Trigunaryyah, 2010). In other words, designing and planning projects not only should be consistent with doing activities related to it (Cox et al., 1997), but also should be conformed to the project's end user. By having a clear understanding of what is expected by superior stakeholders and employers of the project, in the initial phases before construction, one can help creating a detailed design to achieve the ultimate goals of the project (Saghatforoush, 2014). At the moment, projects' documentation doesn't include after construction research. This issue leads to extra costs for the operation and maintenance team (Russell, nd). In the program of operability, stakeholders of the professional operation section in an underlying project cooperate with design and planning team. Agents of the operation section evaluate whether quality and sustainability of the required

operation in the designing and planning projects are considered (Trigunaryyah, 2010). Therefore, a project should be designed and planned in a way that is ideal for final application. To do this, the needs of users and their expectations for project development should be determined. Designers and planners should have a clear understanding of project objectives and its final applications (Davidson Frame, 2003). The ultimate success of the project requires proper implementation of operability, which has been addressed below.

Operability is usually defined as features of design and the setup stages that state the ability of ease of repair. From the user point of view, maintaining a product means increasing its services and reducing its repairs. Finally, repair and maintenance should be cost effective and guarantee that the product is consistent with its required needs (Chen et al., 2003). Maintainability depends on all criteria that can be effective on the main stages of maintenance and various measures that bring the product to its functional status (Coulibaly et al., 2008). According to (Moua et al., 2001), maintainability is a feature of the design and setup stages, which has the ability to maintain or restore a special condition.

Many studies in the past, have investigated the benefits of using constructability in projects. Researchers of these studies have referred to minimizing problems, reducing conflicts, decreasing costs, optimal using of experiences and knowledge of people in the construction stage, reducing changes in the project construction time, improving effectiveness of teamwork, increasing integration among different stages of the project, and many other factors as the benefits of applying this concept (Alinaitwe et al., 2014; Dunston et al., 2007; TDT, 2016; Al-Otaibi et al., 2013). Karim and Magnusson (2008), Dunston (2007), Meier (2000), Karim (2010), D. Silva (2004) consider reducing the risks, increasing knowledge of people, documenting information, reducing costs and time of the project as other benefits of applying operation and maintenance concepts. However, a few researchers have studied these three concepts in an integrated way. The listed benefits in these sources are also the same as the mentioned ones in other studies (Baiden, 2011; Khodadoust, 1976; Mark L. Ogburn, 2014; Meng, 2013; Sarmad et al., 2014; Florence et al., 2014). Moreover, JadidolEslami et al. (2016) in a comprehensive study have investigated three concepts of constructability, operability, and maintainability of the project. Finally, this study presents the benefits of using these concepts in a classification consistent with the initial to final phases of the project (JadidolEslami et al., 2016).

Despite performing different research into the benefits of applying these concepts, their investigation in most of studies has been done in the short term. Considering their importance, it is the minimal effort for understanding and utilizing the functional benefits (Smith, 2013) as, different phases of the project are unaware of the importance of applying these concepts (Meng, 2013). To-date, no comprehensive study has been conducted to examine the benefits of applying constructability, operability, and maintainability concepts together. This issue by itself is the reason for the increase of costs, problems, and duplications in the projects. Therefore, it is required to examine comprehensively the benefits of integration of different stages of the project. By

addressing this gap in the existing Literature, the Authors of this study focused on the benefits of implementing the three concepts of constructability, operability and maintainability, and they achieved this aim by employing a method compatible with this goal, which is presented in the next section.

3. Research Methodology

A systematic process methodology may be used to find the answer of a question or the solution of a problem. In the present study, selection and use of methods of data collection and analysis, was based on their appropriateness to the subject, project objectives, research questions, fields of study, and propositions (Sarmad et al., 2014). Data was collected through library studies. The trend of studies performed about implementing (COM) principles in the construction industry was assessed by Excel software and descriptive and statistical analysis of output diagrams (Khodadost, 1976).

When discussing about data analysis, often it is thought that the aim of data analysis is just statistical methods, whereas this assumption is not correct, and this method is just one of the important methods of data analysis that is usable for researches and data with statistical aspects. There are a lot of researches without statistical aspects. Mainly, they are based on documents and witnesses and rational analysis and understanding. Such researches also follow the complete process of scientific investigation, and include analysis stage (Hafeznia, 2007). In descriptive analysis, if the analysis is in the quantitative form, the researcher summarizes and classifies the collected data by using descriptive statistics. In other words, in the quantitative descriptive analysis, at first the researcher summarizes the collected data by preparing the frequency distribution table. Then, he/she shows them in charts; finally, he/she summarizes them by using other descriptive statistics (Delavar, 2006). However, if it is a qualitative analysis, features of each of the available concepts are explained in the analysis. At this level, semantic system of text or event will be analyzed apart from its social context (Saei, 2007).

Descriptive analysis helps the researcher collect input data appropriately, and after classifying the collected data, he/she will conduct initial analysis on them. In fact, this method is similar to “Basic Vocabularies” of data for further analysis in future (Turner, 1994). This study and those studies considered evaluating the trend in a specific field, are classified in a specific time period, and provide researchers with complete information on the subject, annually (AIA, 2012; Abdirad, 2014; Blanchard, 1999). The next section addresses data analysis of this study.

4. Data Analyses

After evaluating 145 articles related to the benefits of implementing (COM) in the construction industry, the articles were classified by considering the extent of content, and also regarding the aim of this study. It should be noted that all of the evaluated articles in this study have been in the field of the benefits of implementing COM principles, which have been classified based on various indicators such as year of publication, the volume of published articles, fields of study, etc.

The statistical diagrams that will be analyzed in the following show the trend of studies in these articles from

various aspects. Fig. 1 shows the extent of focus of these 145 articles in three COM fields of study all over the world, since 1980, separately.

According to Fig. 1, the volume of the studies related to evaluating the benefits of implementing maintainability is more than other fields of study. The benefits of using constructability concept were relatively well-known. The importance of maintainability was considered gradually. But a small amount of the conducted studies were related to operability. Moreover, the combined implementation of these three concepts is very significant in this form. On the other hand, the reason of fewer studies performed in the field of operation, can be because of the near and inseparable concepts between operability and maintainability, such that in many studies, these two concepts have been considered as a unit. Constructability for the first time was introduced in USA in the 1970s, and has been further developed. Russell and O'Connor are the most prominent researchers in this field. Operability was also introduced in 1950s by USA military services for the first time. Among the prominent researchers in this field are Blanchard & Lowery and Meier, and also Russell. The studies in the field of maintainability commenced in 1967, with Karim and Magnusson in addition, Meng was among the most active researchers in this field. The studies about the effects and the benefits of each of these principles had started since 1980s. Given that the aim of this study is evaluating the trend of studies on the benefits of implementing COM, this decade is considered as the starting point of such studies. Fig. 2 shows the trend of the published studies and articles since 1980s, which is the start of studies related to COM concepts.

Fig. 2 and Fig. 3 show the peak of the studies conducted in the field of COM in 2000s. It has significant differences with two decades before and after it. However, most of the studies conducted in 2000s, have been about constructability and operability and maintainability. In this decade, by considering the world financial crisis, and also spending on employment infrastructures in the construction section (Estache, 2013), much focus was given to developing an appropriate foundation on which to improve this industry. Therefore, many studies have been conducted. As we cannot deny the effective role of implementing COM principles in the progress of the construction industry, significant studies have been done in this field.

Fig. 4 shows the volume of studies conducted in these three fields, separately.

In this figure, classification of different studies is presented based on the number of published articles in the fields of constructability, operability, and maintainability during four recent decades. According to what is seen in the figure, the extent of these studies is different in various time periods and based on its demands in different periods.

Following this diagram, Fig. 3 also shows its overall distribution.

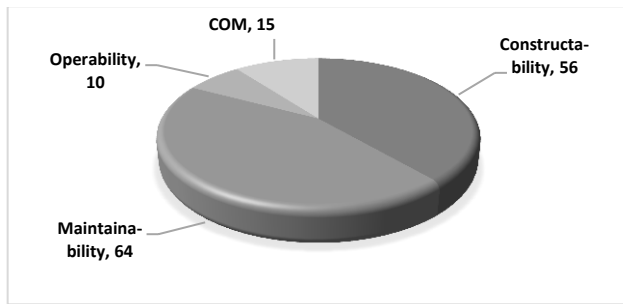


Fig. 1. The extent of focus of articles in three COM fields of study, since 1980 up to now

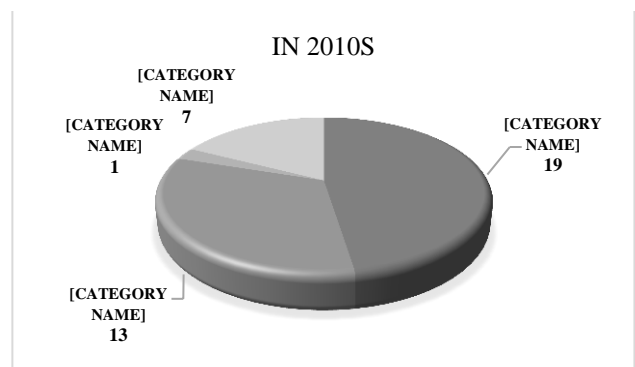
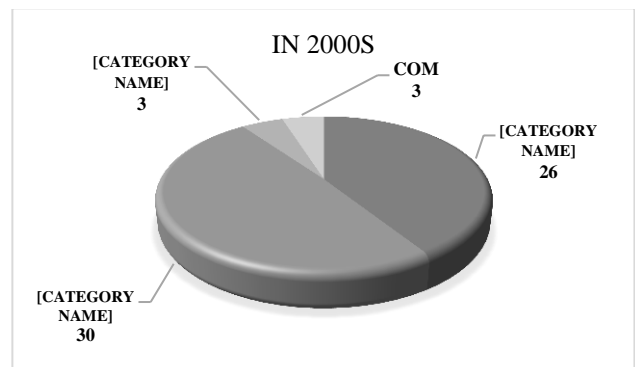
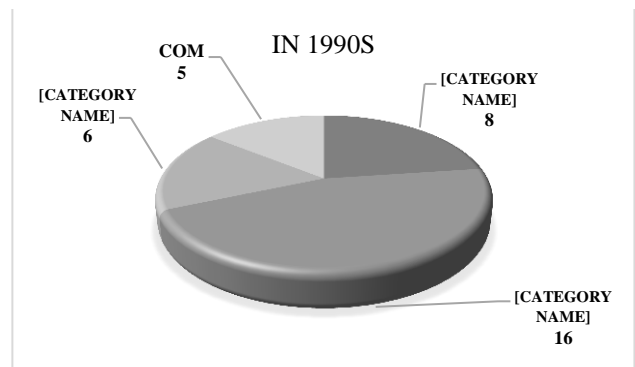
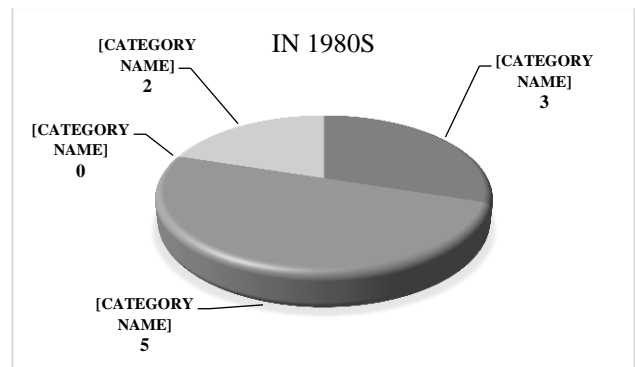


Fig. 4. The extent of focus of articles on the COM concepts, in 1980s, 1990s, 2000s and 2010s

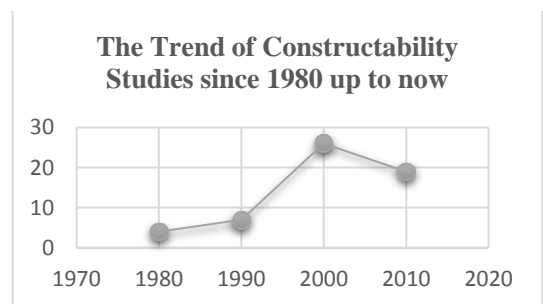
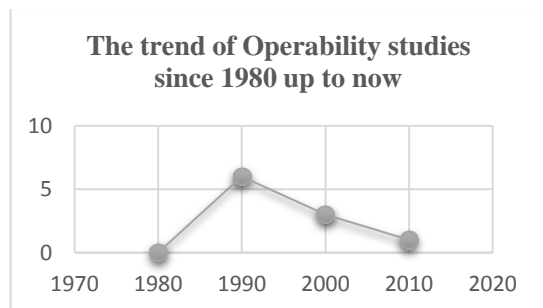
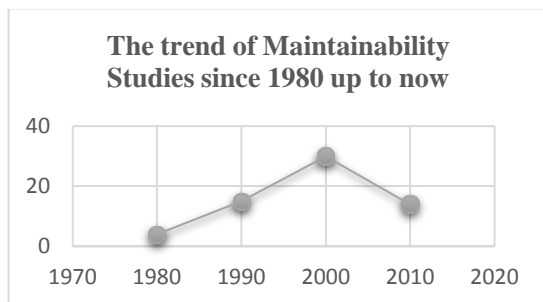


Fig. 2. The trend of the studies in three fields of C, O, M since 1980 up to now

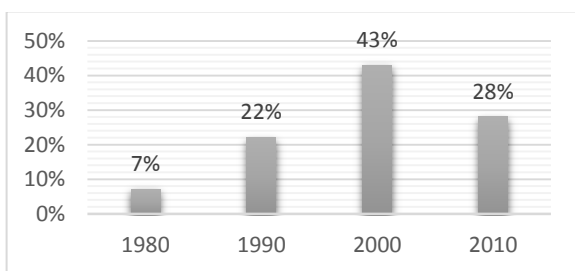


Fig. 3. The distribution rate of the studies conducted in the field of COM since 1980 up to now

According to Fig. 4, since the beginning of COM studies, the focus has been more on maintainability, and understanding its advantages and its effective implementation. Finally, during recent years, by increased awareness of the benefits of implementing all three principles simultaneously, the studies in all these three fields have almost become more balanced and have been considered equally. Given that during the implementation

stage, a huge amount of capital and resources is invested, this phase of any projects has always been important.

The number of studies performed in the constructability filed, is an evidence for this issue. What is less discussed, includes research and investment for design and operation and maintenance phases of the project. According to Fig. 3, in the studies about COM, the amount of focus on the benefits of operability concept has been low. Although over time, this trend has increased slightly, this enhancement is not very significant. This issue by itself confirms that still the benefits of applying operability, have not been understood. Perhaps the development of the studies in this field leads to improvement of the construction process and reduction of problems in this industry.

Fig. 5 shows classification of studies performed in the field of COM globally, and the rate of its distribution.

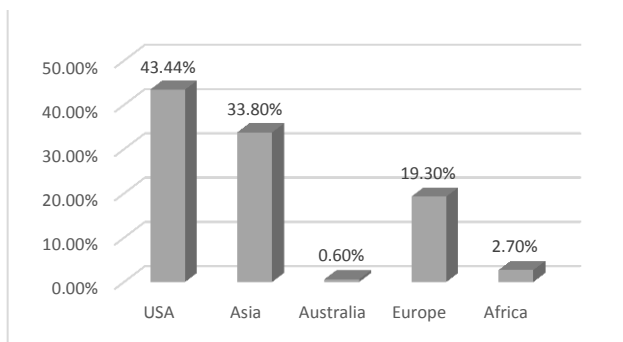


Fig. 5. The distribution rate of the studies performed in the field of COM globally, from 1980 till the present day

What is obvious in Diagram 5, is that most of the studies conducted in the field of COM, have been in USA. Nearly close percentages of development of Asia and Europe to USA, indicate almost synchronous progress of their studies in this field with that of USA. This by itself is the inevitable result of high standards of living all over the world. In return, there is a significant difference between the amount of the conducted studies in this field in two continents of Australia and Africa with other parts of the world. One of the reasons of this difference is the amount of constructions and the extent of the industrial activities in these two continents. On the other hand, the tourism industry in USA and Asia can lead to the construction of larger projects. This increases the need to perform various studies to reduce problems and costs of the projects. Allocating countless annual budget for the construction of civil engineering projects in these continents, increases the importance of paying attention to constructability, operability, and maintainability. Fig. 6 shows the applied domain of COM concepts in the conducted studies.

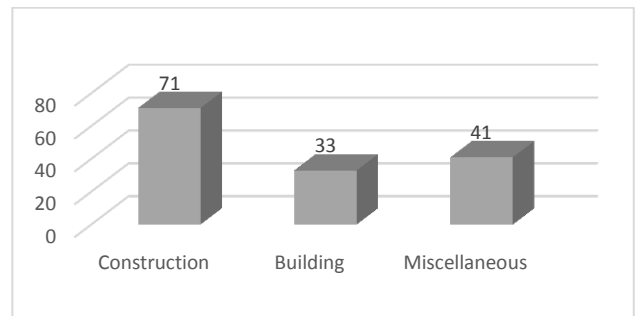


Fig. 6. The applied domain of the conducted studies in the field of COM since 1980 up to now

According to Fig. 6, almost half of the conducted studies in the field of COM, have been related to the building industry. Considering the extent of this industry and the rate of availability of information related to it, this is not far from expectation. However, the growth of studies in other sections except building, shows that the effect of implementing these concepts in other sections has also been considered. Given the nature of the projects, the reason of examining more studies in the field of construction, can be the higher lifetime of this category of projects. On the other hand, the allocated budget to this section has also been more than other industries. If attention is not paid to these concepts, their completion costs will increase. Moreover, the scope and complexity of the civil projects lead to their vulnerability to exposure to various weather conditions. Therefore, there was a need to conduct further studies.

According to the overall assessment of the discussed articles, Fig. 7 shows the 10 top benefits of implementing COM concepts and the emphasis of these benefits in the mentioned articles. The specified percentages in the following diagram show the share of articles including these benefits from 145 reviewed articles.

According to the results, another comprehensive study conducted by the researchers of this study, in which the benefits of using COM concepts from the initial phases of the project to the end were identified, classified, and analyzed through meta-synthesis method (JadidolEslami et al., 2016). The most important benefits are presented in Fig. 7.

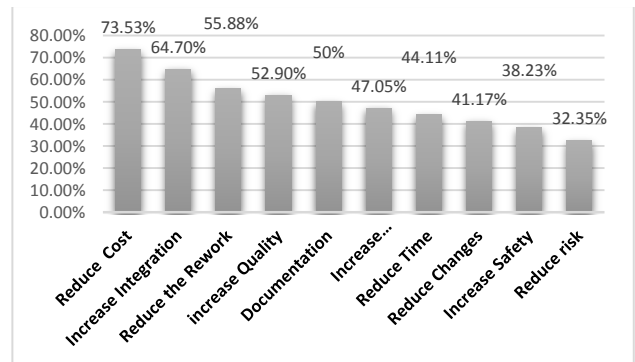


Fig. 7. The most obvious benefits of implementing COM concepts since 1980 up to now

In Fig. 7 it can be seen that one of the most obvious benefits, which have been addressed, is the reduction of

costs and increase of integration and coordination due to implementing COM principles. The effective role of applying COM concepts in reducing duplications and increasing the quality of the project output is undeniable. Implementing these principles leads to facilitating communication, reduction of delays and changes, and reduction of project risks, and increase of safety in the project. The reviewed articles refer to other benefits, including creating a knowledge base, effective use of experiences, increasing productivity, optimal use of modern technology, evaluating feedback, increasing innovation, and early detection of problems. Fig. 7 has just pointed to ten top benefits.

In previous studies, a large portion of these benefits have been considered in two stages of design and implementation that somehow show the importance of performance in these stages. But as it is obvious in the diagram of Fig. 7, the focus of these benefits is on two phases of design and implementation. This problem due to this fact that most of the estimations and predictions in the early stages of the project are not accurate and realistic. Thus, the influence of opinions of contractors and executors in determining the qualitative and administrative characteristics and also the final costs, is high in the early stages of the project. By the progress of the project, the time interval between prediction and implementation is reduced and enforcing comments by stakeholders are less, too. In addition, based on tangible realities of the project, characteristics and performance of its various stages are determined. There are many other benefits related to implementing maintainability principle, which are addressed by other researchers. What is considered by authors of this study, is that a huge portion of these benefits is observed in the operation phase (JadidolEslami et al., 2016). According to lack of sufficient attention to this principle in most of the projects, it should be examined more comprehensively. If it is implemented, it may lead to significant reduction of costs, duplications, and risks of the project.

5. Conclusion and Suggestions

Considering the studies that have been conducted in the field of evaluating the benefits of implementing constructability, operability, and maintainability, it can be concluded that the focus of most of them has been in the USA (61 articles from 145). The earliest studies were in the 1980s. The peak was in the 2000s and coincided with the beginning of economic recession all over the world and the need to pay attention to the effective factors on reducing the problems of underlying projects and improvement of the construction industry. Most of these studies are related to the building section. However, we cannot deny their effective role on other sections of the Industry, such as dam construction, road construction, etc.

The results of this study show that in comparison with the past, the necessity of paying attention to what is facilitating the construction process, has been understood more than before. This indicates attention and interest of the professional community of the construction industry, to change the old methods and to use new methods such as COM principles.

The beginning of COM studies has been with defining the principles and framework of these concepts. Researchers in later studies paid attention to identifying the advantages and disadvantages of implementing these

concepts. Today, most of the studies are in the field of finding solutions to resolve the barriers and to facilitate implementing these principles, in different ways.

Considering that most of project problems, such as time and cost exceed, lack of design and procurement integration and weak implementation systems, are as the result of lack of proper information sharing and inefficient relationships between the design and construction teams, a major share of the benefits of implementing COM principles can significantly affect the process (George Jergeas, 2001; Dunston et al., 2007; Henry Alinaitwe, 2014; TDT, 2016; Deborah J. Fisher, 2000). Highlighting these two benefits will cause encouragement of employers to apply these principles and also an appropriate foundation to facilitate its implementation.

Nowadays, current existing viewpoints on project management problems causes separation of project phases, since early stages to the end. As the result of that, project stakeholders have different expectations from each other which make the work harder. Integrating project phases simply provides faster project target achievement and success. Next paragraph highlights various benefits taken from pushing project stakeholders to collaborate with each other throughout the project life cycle.

Benefits such as reducing duplications, increasing the quality of output, improving documentation, facilitating communication, and reducing changes and delays are among the benefits referred to them in the reviewed studies. The focus on the benefits of implementing these concepts and evaluating the effectiveness of each of these strategies and benefits, in different stages of the project, can help managers functionally. They can increase the efficiency of the projects.

The results of this study can provide research contexts for future trends and opportunities. Future studies aim to investigate the benefits of COM principles more comprehensively, particularly in projects, in which COM is implemented and their results are evaluated quantitatively. According to the evaluation process of the benefits of implementing COM, a large portion of these benefits are evident in all phases of the project from the beginning of feasibility studies to operation and maintenance phases. Considering this issue, the effect of implementing COM is prominent in determining qualitative and implementation characteristics and also the final cost and time of the project. Awareness of the benefits of COM and correct understating of the benefits of implementing these principles, will make realization of project objectives and success more possible. In this regard, the benefits of applying COM in various phases of the project are also more tangible.

6. Contribution of the Research to Academics and Practitioners

1. According to the effective role of implementing COM concepts in reducing problems of the construction industry and its direct effect on increasing efficiency and profit, it is suggested that studies in this field be undertaken, particularly operability studies. Functional areas to implement these concepts and

their facilitation should be provided through different sciences.

2. Most of the conducted studies to-date had qualitative results. Focus on the quantitative results of implementing these principles will be useful for increasing the motivation of employers. Therefore, it is suggested that future studies pay more attention to quantitative methods in the field of COM principles.
3. Case studies will provide valuable experiences to the contractors and owners about implementing COM principles in practice. In some projects, COM principles were not implemented in all stages; for example, these principles were used just during operation and maintenance phases. It is suggested that future studies evaluate several case studies to provide their benefits to stakeholders, tangibly.

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