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# Analysis of Causes of Delays and Cost Overruns as Well as Mitigation Measures to Improve Profitability and Sustainability in Turnkey Industrial Projects

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**Abstract:** Delays and cost overruns in turnkey projects can lead to significant economic losses, disputes and even project abandonment. These facts negatively impact the environmental, social and governance (ESG) policies of companies involved in the project. In this paper, a bibliographic review was conducted to identify the leading causes of delays and cost overruns in turnkey industrial projects in the refining, gas and conventional electricity generation (RGE) sector and propose good practices to avoid or mitigate them. We identified 893 causes of delays and cost overruns and 147 mitigation measures. The causes and mitigation measures were grouped into eight categories based on the execution phases of an RGE project. A critical analysis was carried out to avoid duplication, and the result was evaluated by experts in turnkey project management, reducing the causes and mitigation measures to a final set of 103 and 49, respectively. The construction category showed the most significant influence on project delays and cost overruns, and this, together with the preliminary phase and project management categories, contributed to 60% of the identified causes. The findings of this study can help project managers improve the profitability of turnkey industrial projects, promoting innovation and sustainability within companies and society.

**Keywords:** project management; ESG; causes; mitigation measures; delays; cost overruns; turnkey project; refining; gas; electricity

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## 1. Introduction

Civil and industrial construction activity is vital to the global economy, with construction-related spending accounting for around 13% of global GDP. According to data from Deloitte in its annual publication *Global Powers of Construction* for the year 2022 [1], the total revenues of the construction sector amounted to USD 1.5 trillion. However, the construction business has a long history of low productivity [1–3]. Delays and cost overruns in executing construction projects are a reality, regardless of the type of industry or country. In fact, projects that are executed on time and/or within the contractual budget are exceptional cases.

Additionally, more and more companies are considering the sustainability of their activities in their decision-making policies. Sustainability implies paying more attention to the environmental aspects of their activities and ensuring the efficient use of resources in implementing industrial projects. In this sense, delays and cost overruns negatively affect the sustainability of these industrial activities, delaying the population's access to new infrastructures, technologies, processes and clean and efficient energies. Therefore, avoiding delays and cost overruns in industrial projects contributes directly to achieving the Sustainable Development Goals (SDGs) established by the United Nations, especially SDG 7 (Affordable and Clean Energy) and SDG 9 (Industry, Innovation and Infrastructure).

According to McKinsey Global Institute [2], USD 1.6 trillion a year could be generated through productivity improvements, like those in other sectors. This amount would be equivalent to Canada's GDP to cover half of the world's infrastructure needs or to boost global GDP by 2% per year.

On the other hand, the global average growth of labor productivity in construction has increased by only 1% per year over the last two decades, remaining stable in most advanced economies. In contrast, the world economy has grown by 2.8%, and manufacturing by 3.6%. These data indicate that the construction sector is underperforming and has ample room for improvement [2].

Regarding the oil and gas sector, Ernest & Young, in its series of studies "Spotlight on Oil and Gas Megaprojects", found that 78% of the projects had cost overruns, and 65% were significantly delayed [4]. Furthermore, in the specific case of this sector, avoiding delays and cost overruns is critical to ensure the sustainability of the energy supply chain [5].

The problem raised by delays, cost overruns and low productivity was studied by Kerzner as early as 2009, who proposed that the solution lies in better control and use of corporate resources [6]. This idea is directly related to implementing a relatively modern project management methodology. Sixty years ago, it was limited to the US Department of Defense construction companies and contractors. Today, project management is being applied in industries and organizations as diverse as defense, construction, pharmaceuticals, chemicals, banking, hospitals, accounting, advertising, law, the United Nations and state and local governments [6].

In this context of diverse and complex projects, both training and information play a fundamental role in their execution, and it is essential to possess the essential knowledge for correct management. According to the Project Management Institute [7], it can be stated that the execution of a project is defined by three basic parameters, also called "triple constraint", "golden triangle" or "project management triangle", which are the scope, the deadline and the cost of the project. A change in any of the three parameters will have an inverse impact on at least one of the other two. For example, if the same scope requires a reduction in the execution time (shorter time), the budget for the work will have to be increased (higher cost), as more resources will have to be allocated.

All projects carried out in the refining, gas and conventional electricity generation sectors (activities grouped under the generic denomination of RGE in this paper) obtain the funds for their execution from an external (banks, funds, etc.), internal (production or sales departments finance the project) or mixed financing scheme. The budgets for these projects can range from tens of millions of dollars, as in the case of cogeneration plants, to billions of dollars for a complete refinery. For any financing institution, an increase in the project term or cost will negatively impact the financial viability parameters and could put the viability of the business plan linked to the project at risk.

On the other hand, worldwide demand for energy and oil and gas products has grown steadily. Projects in the RGE sector are usually executed through turnkey contracts, also known as EPC (engineering, procurement and construction) contracts, as they are preferred by financial institutions when it comes to providing funds for the execution of infrastructures.

In this type of contract, a specialized contractor assumes the entire project execution risk, including the engineering, procurement, construction and commissioning phases, for an industrial client. Of course, these contracts cover scope, time and cost, with very high penalties for not complying with requirements. Oil and gas EPC megaprojects (projects with more than USD 1 billion of investment) often experience cost overruns due to delays in their planning [8]. Incurring cost overruns and/or delays during execution, without proper management between the parties, can lead to disputes, arbitration, litigation and ultimately total project abandonment.

Usually, the successful outcome of any project and EPCs is measured through compliance with the triple contractual constraint, which includes the previously mentioned parameters of scope, schedule and cost. However, sometimes, given the complexity of specific projects, it is necessary to incorporate other criteria or critical success factors (CSFs) to address specific sectors rigorously. Not all CSFs contribute to project success in the same way, and the contribution will differ depending on the type of project [9]. For example, environmental management in oil and gas EPC projects accounts for at least 0.87% of the total project budget [10]. It may seem like a small amount of money, but when we are talking about a sector that strives to have no less than 4% margins, we are talking about almost 25% of that margin.

In this scenario, some studies deal with delays and cost overruns in projects of the civil construction sector [11,12] or corresponding to case studies of specific projects or countries [13,14]. However, there is a lack of systematic studies on the causes of delays and cost overruns in EPC projects, especially in the RGE sector. This work aims to fill this information gap and to identify, in a systematic and structured way, the causes of delays and cost overruns that have the most significant impact on the time and cost parameters of the golden triangle of EPC project management in the RGE sector, as well as the proposed mitigation measures to avoid them. Additionally, this work aims to determine the relative importance of the identified causes and measures and to structure them from the perspective of the professional practice of an EPC company.

To achieve the above objectives, this work carried out an exhaustive bibliographic search on delays and cost overruns and their mitigation measures as a first step of a global investigation developed to define a methodology to mitigate delays and cost overruns in RGE EPC projects. This bibliographic review allowed for the design of a questionnaire subjected to analysis by a group of experts, obtaining a set of significant causes and mitigation measures. Finally, these were systematically classified into a structure proposed by the authors.

## 2. Materials and Methods

The approach to a literature review should follow the following three search criteria: (1) it should be of great interest to the authors and the scientific community or readers, (2) the subject matter should be of the proper scope, and (3) it should belong to a field of research that has not yet been exhausted [15]. In the present work, a bibliographic search was carried out in the Scopus, Web of Science and Teseo (including the doctoral theses in Spain) databases.

According to the first criterion and based on the research topic of this work, the bibliographic search dealt with industrial projects in EPC mode. According to the second criterion, the delays and cost overruns of these projects were studied. According to the third criterion, the search was limited to projects in the RGE sector.

These three criteria were concretized through the following set of keywords:

- Criterion 1/project type: project; EPC project; turnkey project.
- Criterion 2/scope of review: delay; schedule; cost; budget; cost overruns; budget overruns; risks.
- Criterion 3/sector delimitation: industrial; petrochemical; petroleum; power; oil and gas.

The search was performed in the fields of title, abstract and keyword of scientific publications referred to in the databases mentioned above, and the method was based on finding at least one keyword from each search criterion, giving a total of 105 possibilities ($3 \times 7 \times 5$). With all these combinations of keywords, the aim was to obtain all the publications that can provide information, even if minimal, to cover the objectives of the work.

Once the search was completed, a critical reading of the publications was carried out to select only those that addressed the problem of delays and cost overruns in industrial projects, which is the subject of this paper. Within the selected publications, three aspects were analyzed in detail: (1) the causes of delays and cost overruns described, (2) the mitigation measures to avoid them and (3) the classifications proposed by the works to group these causes and mitigation measures.

Once all this information was collected, a filtering analysis step was added to reduce, group and classify the causes of delays and cost overruns and the mitigation measures found in the literature. Reducing the number of causes and mitigation measures was carried out by eliminating duplicates and grouping under a single denomination those causes and mitigation measures that, despite having different names in the bibliography, refer to the same concept. Once this reduction was carried out, the resulting causes and mitigation measures were grouped into 8 categories corresponding to the EPC project life cycle phases. Based on the results of this categorization of causes and mitigating measures, a questionnaire was designed to establish their relative importance from the perspective of the professional practice of the industrial sector. The questionnaire included an open response section where respondents could provide comments and suggestions based on their professional experience.

Thus, the last stage of this process consisted of a survey using the designed questionnaire, which was sent to a small group of 10 EPC project managers with more than 20 years of experience. The questionnaire used a rating scale from 1 to 5, where 1 corresponds to the minimum and 5 to the maximum value, to rank the importance of the causes of delays and cost overruns and the selected mitigation measures. Then, the answers to the questionnaire were analyzed using the relative importance index (*RII*) (Equation (1)):

$$RII = \frac{\sum X}{Y \cdot Z} \tag{1}$$

where $X$ is the weight given to a factor by a respondent (range 1 to 5), $Y$ is the highest score available (5 in this case) and $Z$ is the total number of respondents who answered the question. The use of *RII* to obtain the most significant factors has been commonly used in the project management literature [16]. With the survey results, a final classification of the causes and mitigation measures was elaborated, discarding those that obtained an *RII* value lower than 0.85.

## 3. Results and Discussion

As a result of the bibliographic search, a total of 158 references were found. After a critical reading of these works, 96 publications were selected, fulfilling the three established search criteria addressing the problem of delays and cost overruns in projects.

Of these 96 publications, only 27 provide causes of delays and cost overruns and/or mitigation measures [2,11–14,16–37] and only 10 define a category structure to classify the listed causes or mitigation measures [13,14,16,18,20,23,29,33,36,37] (Table 1). A total of 893 causes of delays and/or cost overruns and 147 mitigation measures for these delays and cost overruns were collected from these references (Table 2).

In general, the literature does not distinguish between delays and cost overruns or refers only to delays, with the cost overrun being a consequence of the failure to meet the deadline; only seven references deal specifically with cost overruns.

### *3.1. Geographical Distribution of Publications*

The geographical origin of the 96 publications was analyzed, grouping them by region. The principle followed to assign a reference to a country was as follows. First, if the reference only studies projects from one country, it is assigned to that country. If there is no mention of the location of the projects studied, the country of the institution of the first author of the publication is assigned.

The countries that contributed to each geographic region are as follows:

- Europe (12 countries): Spain, Finland, France, Greece, United Kingdom, Germany, Sweden, Lithuania, Czech Republic, Slovenia, Norway, Turkey.
- Africa (two countries): Egypt, Libya.

– Americas (seven countries): Canada, United States of America, Argentina, Colombia, Chile, Ecuador, Uruguay.
– Middle East (five countries): Saudi Arabia, Kuwait, Iraq, Iran, United Arab Emirates.
– Asia (eight countries): India, Indonesia, China, Japan, Malaysia, Korea, Singapore, Taiwan.
– Oceania (two countries): Australia, New Zealand.

Therefore, the 96 analyzed references cover 37 countries, representing the data in Figure 1. The 27 publications that provide causes of delays and cost overruns and/or mitigation measures come from 21 countries. The 10 publications defining a category structure for the listed causes of delays and cost overruns and/or mitigation measures are distributed across six countries.

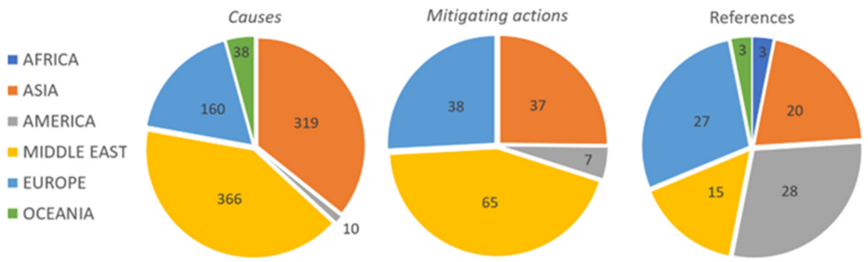


**Figure 1.** Geographical distribution of causes of delays and cost overruns (**left**), mitigation measures (**center**) and bibliographic references (**right**).

It is observed that there are broad geographical areas in which no research papers or reports related to EPC projects have been identified, which is consistent with what has been described in previous works [31].

Although the number of references from the Middle East is relatively low (15.6%), these papers propose the highest proportion of causes of delays and cost overruns (41.0%) and of mitigation measures (44.2%). At the other extreme, the geographical area of the Americas accounts for 29.2% of the publications but only proposes 1.1% of causes of delays and cost overruns and 4.8% of mitigation measures.

Europe and Asia have a similar percentage of bibliographic references to the Americas, with 20.8% and 28.1%, respectively, but provide a significant proportion of causes (17.9% and 35.7%, respectively) and mitigation measures (25.9% and 25.2%, respectively).

### 3.2. Bibliographic Analysis

In order to categorize the causes and mitigation measures in a sufficiently robust way, it is necessary to define and understand the most important causes of delays and cost overruns. Therefore, in the last decades, the literature has dealt with this topic from a myriad of points of view for different sectors and projects. The bibliographic search results are presented below for the 27 references mentioned above, which are classified according to the publishing house or institution of publication.

The Society of Petroleum Engineers has published articles on this topic in recent years with contributions from several authors from different associations [32,38,39], although the last two publications do not present causes or mitigation measures. ADNOC Group, Akhtar, in 2020, summarized the current problem of delays and cost overruns in projects [38]. The author addressed the problems and challenges of EPC project management with a case study on petrochemical, oil and gas EPC projects in the Middle East. The methodology adopted consisted of surveys, interviews and case studies, which allowed him to conclude that although each project has its challenges, many causes of cost overruns and delays are common to most of them.

In 2019, the National Petroleum Construction Company established the contribution of hybrid contracts to EPC projects by enabling early engagement in the FEED (front end engineering design) phase. In the publication, the authors compared traditional contracts with three case studies in which different hybrid contracts were implemented: "Lump sum contract through Early Engagement", "Combined FEED & EPC contract through OBE" and "EPC contract through FEED Competition" [39].

Similarly, Kuwait Oil Company published in 2016 how to control major oil and gas EPC projects through strategic and innovative project management practices [32]. To do so, the authors identified the most frequent causes of delays through a project life cycle analysis to segregate the most significant causes and mitigation measures for each phase of the projects, analyze them and establish a series of "best practices".

For its part, McKinsey Global Institute published in 2017 [2] an executive summary with various economic data on industrial activity and its production in the construction sector. Also, it established seven mechanisms to drive productivity improvements in the industry and address the ten causes of low productivity in the construction sector that they identified.

The Multidisciplinary Digital Publishing Institute (MDPI) has addressed the issue of delays and cost overruns in projects with at least two publications in the journals *Buildings* [13] and *Energies* [17], both of which addressed the Arabian oil and gas construction industry. The first is one of the few publications that addressed the statistical study of the population in order to determine the sample size necessary to obtain reliable results [13]. The authors identified 29 causes of delays, grouped into seven categories, and nine causes of cost overruns. The second publication identified 23 causes, which it analyzed statistically by measuring the impact, with frequency and importance, through surveys of local experts involved in constructing petrochemical projects in Saudi Arabia [17].

The UK publisher Taylor & Francis has also contributed to the state of the art with publications in at least four journals: *International Journal of Construction Management* [33], *Journal of Transnational Management* [34], *Journal of Chinese Institute of Engineers* [35] and *Construction Management and Economics* [36]. All four publications addressed the specific topic of a country of study, i.e., India in 2020 [33], Iraq in 2019 [34], Taiwan in 2017 [35] and the United Arab Emirates (UAE) in 2006 [36]. For the case of India, a statistical analysis using the *RII* and fuzzy ranking was employed to identify, evaluate and prioritize delays and causes in the context of the Indian construction industry. As a result, they obtained 48 causes of delays, which they grouped into six categories [33]. As for Iraq, Oman and Iran, the authors conducted a literature review where the causes of delays were extracted. As a result, the work established the main causes of delays in projects of the Iraqi oil and gas industry [34].

The Taiwanese researchers' publication used a Monte Carlo simulation to identify and analyze the causes and mitigation measures associated with a basic design engineering (BDE) project for a petrochemical plant in Taiwan and managed to list three sets of causes [35].

Unlike the previous publication, the UAE authors started from 44 causes of delays in eight categories. Through randomly distributed surveys of construction professionals (seven clients, 46 consultants, and 52 contractors) in the UAE construction industry, they determined the 10 most significant causes for their country, plus Saudi Arabia and Lebanon. In addition, they concluded that the UAE shared only three of the top ten causes with the other two countries. Finally, as a result, they provided five mitigation measures to minimize the impacts on the UAE [36].

The other British publisher, Emerald Group Publishing, also has publications on the subject in at least three journals: *International Journal of Energy* [37]; *Journal of Financial Management of Property and Construction* [18]; and *Journal of Engineering, Design and Technology* [19]. All three publications addressed the specific topic of a country of study: Iran in 2020 [37], India in 2018 [18] and Sweden in 2008 [19].

In the Iran research, the fuzzy Delphi method was used to identify 75 causes within eleven categories and then prioritize them through the best-worst method [37]. For their questionnaire, they relied on the opinions of 10 experts from the National Iranian Oil Engineering and Construction Company (NIOEC) with 10 to 30 years of experience in different areas of oil projects, such as project management and engineering. They concluded a series of recommendations to minimize and control delays in oil and gas construction projects in Iran.

Although the research focused on India dealt with construction in general, it did an excellent bibliographic review and provided tables with delays by sector, corrective actions and 60 causes of delays grouped into seven categories [18].

In the first phase, the authors who studied the case of Sweden carried out a bibliographic review of 40 publications and selected 16, from which they extracted 250 factors or criteria [19]. In the second phase, they conducted 23 semi-structured interviews with professional client organizations with long-term experience in construction projects, and most of them belonged to the senior management level within their organizations (12 people belonged to public organizations and 11 people to private companies). These interviews allowed the first 12 factors in each category to be considered, reducing the list to 58.

The Dutch publisher Elsevier covered the subject in *International Journal of Project Management* [20–23]. However, the journal *Computers in Industry* also contributed to the state of the art, but differently: it dealt with applying Bayesian networks to improve the management of causes and mitigation measures [24]. The methodology was repeated: a brief literature review of the country in question, followed by a process of reduction or ranking of causes (and mitigation measures in some cases) through statistical methods or expert judgment. In the specific case of Elsevier, the studies for India in 2011 [20], Malaysia in 2006 [22] and Saudi Arabia in 2005 [23] were addressed. However, a publication covered international projects in Asia [21].

In 2017, the US publisher Sage published an article on project management in the petrochemical industry, specifically on Saudi Arabian projects, in *International Journal of Engineering Business Management* [25]. A multi-criteria model was used to process information from the companies, identifying 15 barriers and nine enablers to the success of these projects.

In addition to publishers, research associations, such as ARCOM in 2008 [26]; professional societies, such as the IEEE Computer Society in 2010 [27]; and professional associations, such as the ASCE in 2002 and 2013 [16,28], have contributed to the state of the art. From ARCOM [26], a FEED vs. FEED and EPC comparison was carried out, and the similarities and differences between projects in the construction and oil and gas sectors were studied. On the other hand, from China [27] 16 "best practices" were grouped according to the three EPC phases: five for engineering, five for procurement and six for construction.

Regarding ASCE, the Taiwanese authors [28] analyzed four case studies, noting that delays and cost increases are related, and they grouped 10 causes into the following three categories: compressible or client causes, inexcusable or consultant causes and excusable or external causes. Finally, the Turkish publication [16] presented 83 causes grouped into nine categories illustrated in a fishbone or Ishikawa diagram. The methodology consisted of a literature review and interviews with experts in the construction sector, quantifying the delay factors according to the relative importance index to establish 12 recommendations for civil construction projects.

### *3.3. Identification and Classification of Causes of Delays and Cost Overruns as Well as Mitigation Measures in Industrial Projects*

#### 3.3.1. Definition of Categories for Classifying Causes and Mitigation Measures

In order to facilitate the understanding of the causes and mitigation measures of delays and cost overruns in industrial projects found in the literature review, a classification structure is proposed in this paper.

It has been considered that an individual cannot simultaneously compare more than seven (±two) items with satisfactory consistency, and, therefore, hierarchical decomposition is desirable [40]. For this reason, this paper proposes a classification structure of delay and cost overrun causes and mitigation measures consisting of eight categories that may have a repercussion or impact on project cost or schedule. This structure was established based on the phases of the life cycle of an RGE project [38,39,41,42] and the main stakeholders in each phase of an EPC project. The eight categories are as follows:

1. Preliminary phase: includes those factors generated before the contract's signing (negotiation phase) between the company that carries out the project (EPC contractor) and the client.
2. Engineering: includes those factors that occur or originate during the development of the detailed engineering phase by the EPC company.
3. Procurement: includes those factors that occur during the purchase and supply of equipment and materials by the EPC company.
4. Construction: encompasses those factors that occur or take part in the construction up to the handover of the facility.
5. Handover: groups those factors that occur while transferring the operating systems from the EPC contractor to the client.
6. Project management: encompasses the factors within the project's scope and executed by the EPC contractor.
7. Client: includes the factors within the project's scope and depends on who commissions the project.
8. External factors: include factors that do not depend on the parties or stakeholders involved in the execution of the project (plant owner, EPC contractor, investors, etc.) but affect the results of the project execution.

Table 1 shows the equivalence between the eight-category classification structure defined in this paper and the classification categories presented by the 10 selected articles.

**Table 1.** Equivalence of categories for the classification of causes of delays and cost overruns as well as mitigation measures.

| **Categories Defined in This Work** | **Categories Defined in the Bibliographic References** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | [16,23] | [37] | [18] | [33] | [14] | [20] | [36] | [13] | [29] |
| Preliminary phase | Consultant | Consultant | | Consultant | | | Contractual relationship | Contract | Contract |
| | | Contract and contractual relations | Contract management | Tender related | | | Consultant/designer | Consultant/designer | Consultant/designer |
| Engineering | Design | Design | Planning, design and engineering | Design | Engineering | Process | | | |
| | | | | | | Technical issues | | | |
| Procurement | | | Procurement | | | | | | |
| | Equipment | Equipment | | Equipment | | | | | Plant/equipment |
| | Material | Materials | | Materials | | | | | Materials |
| Construction | Labor | Labor | | Labor | | | | | Labor |
| | | | | Construction methodology | | | | | |
| | | | | | | Site | | | Sub-contractor |
| Handover | | | | | | | | | |
| Project management | Project | | Project execution | | Project | Project | Planning and scheduling | All parties | Project planning |
| | Contractor | Contractor | | Contractor | Contractor | Authority | Contractor | Contractor | Contractors |
| | | | Human resources | | Resources | Human | | Resources | Coordination |
| | | | Financial | | | | Financial | | Financial |
| Client | Owner | Owner | Financial | Client | Client | Human | Owner | Owner | Client |
| | | | Human resources | | Resources | | Financial | Resources | Financial |
| External factors | Externality | Laws and regulations | External | | External | | Government regulations | External | |
| | | Environmental factors | | | | | Unforeseen conditions | | |

Table 1 shows that seven of the 10 publications defined categories related to consulting, bids and contracts, which have been included in this work within the preliminary phase category, indicating the importance of these early stages of the project in the outcome of the project.

In six of the 10 publications, categories were defined under the design, planning, engineering, processes and technical aspects, which have been included in this work in the engineering category. Only five of the 10 publications defined categories related to equipment and materials, which have been grouped in this work in the procurement category.

The categories in the literature under labor and construction methodology, in addition to those related to the plant location and which appear in six of the 10 publications, have been grouped in this paper in the construction category.

None of the 10 publications defined categories that could be included in the category of handover, which the authors of this paper believe should be taken into account, as shown in Table 3.

The 10 references included categories that can be included in the categories defined in this paper as project management and client. The human resources and financial categories, depending on whether they refer to the client or the EPC company, have been included respectively in the client and the project management categories defined in this paper.

Finally, the external factors category was only defined in six of the 10 references, including environmental factors, legislation and regulations and contingencies.

#### 3.3.2. Analysis and Classification of Causes and Mitigation Measures

The initial literature review identified 893 causes of delays and cost overruns and 147 mitigation measures, as shown in Table 2. In order to systematically reduce the high number of causes and mitigate the measures identified, a process of successive approximations was followed.

In the second stage, filtering was performed in which the causes and mitigation measures repeated in several studies were eliminated, reducing the number of causes of delays and cost overruns by 52%, to a total of 432 causes; the number of mitigation measures was reduced by 5%, down to 140.

**Table 2.** Evolution of the number of causes of delays and cost overruns as well as mitigation measures in the successive stages of the classification process.

| Stages of Classification | Causes | Mitigation Measures |
|---|---|---|
| 1. Result of the bibliographic search | 893 | 147 |
| 2. Result after eliminating duplicities | 432 | 140 |
| 3. Results after authors' analysis | 103 | 49 |

In the third stage, to further reduce and classify the causes of delays and cost overruns as well as mitigation measures, a survey was conducted among a small group of experts consisting of 10 EPC project managers with more than 20 years of experience. As a result of this survey, and using the *RII* as a selection criterion, the causes and mitigation measures whose *RII* was less than 0.85 were discarded; 326 causes and 76 mitigation measures were thus discarded. On the other hand, three new causes and 15 new mitigation measures proposed by the authors, which were not described in the literature, were included. As a final result, a total of 103 causes of delays and cost overruns and 49 mitigation measures are proposed, listed in Tables 3 and 4, respectively. These represent a reduction of 88% of the causes and 67% of the mitigation measures collected in the literature search.

The 103 causes of delays and cost overruns and the 49 mitigation measures were classified into the eight categories proposed in this work. To increase the contrast and facilitate the understanding of the causes of delays and cost overruns, given their high number, a second level of classification was proposed for some of them, adding a total of 12 subcategories, also shown in Table 3. The comments in the open response section, given by the group of experts during the survey, helped define these subcategories.

In general, the results indicate that for the categories that included more causes, a more significant number of mitigation measures was also proposed. The construction phase has the highest number of causes of delays and cost overruns plus mitigation measures, with 24.3% and 20.4%, respectively. Secondly, the importance of the initial aspects of the project, included in the preliminary phase category, is reflected in the 16.5% of causes and 14.3% of mitigation measures, as well as the project management by the EPC contractor, with 17.5% and 16.3% of causes and mitigation measures, respectively. These three categories account for almost 60% of the causes of delays and cost overruns and 51% of the mitigation measures. The categories corresponding to handover and client account for the lowest number of causes, with 3.9% and 6.8%, respectively. The remaining categories (engineering, procurement and external factors) are in an intermediate situation, accounting for 8.7%, 11.7% and 10.7%, respectively, of the causes of delays and cost overruns.

**Table 3.** Causes of delays and cost overruns proposed in this work.

| Category | Subcategory | | Cause | |
|---|---|---|---|---|
| Preliminary phase | FEED and technical documentation | 1 | Definition of the deficient project | |
| | | 2 | Omissions in key documentation | |
| | | 3 | Lack of data for estimating the duration of the main activities | |
| | | 4 | No end-user involvement in the definition of the project | |
| | Bidding process | 5 | Long bidding process (> 12 months) | |
| | | 6 | Exceptionally low offers | |
| | | 7 | Excessive number of bidders | |
| | | 8 | Unrealistic project timeline | * |
| | Financial factors | 9 | Client's financial difficulties | |
| | | 10 | EPC contractor's financial difficulties | |
| | | 11 | Financial difficulties of prime contractors | |
| | | 12 | Negative cash flow | |
| | | 13 | Poorly defined payment milestones | |
| | Contract | 14 | Discrepancies in the contractual documentation | |
| | | 15 | Late penalties and/or ineffective early delivery incentives | |
| | | 16 | Poorly defined deliverables | |
| | | 17 | Unreasonable allocation of risk to the EPC contractor | |
| Engineering | | 18 | Technically complex project | |
| | | 19 | Technical specifications or legal requirements are poorly defined or do not reflect client requirements | |
| | | 20 | Changes in specifications, data sheets or materials | |
| | | 21 | Inadequate design | |
| | | 22 | Incomplete drawings/documents | |
| | | 23 | Lack of experience of the design team | |
| | | 24 | Shortage of experienced and qualified technicians | |
| | | 25 | Design changes | |
| | | 26 | Delays in the production of documents/plans | |
| Procurement | General | 27 | The list of suppliers is very limited by the client | |
| | Unreliable suppliers | 28 | Unreliable suppliers on deadline | |
| | | 29 | Unreliable suppliers in price | |
| | | 30 | Technical requirements | |
| | | 31 | Late awarding LLIs (long lead items) | |
| | | 32 | Prices higher than those considered in the contract budget | |
| | | 33 | Delivery times longer than those considered in the contractual schedule | |
| | | 34 | Complicated customs management | |
| | Transportation | 35 | Expensive transportation | |
| | | 36 | Transportation | |
| | | 37 | Transport with unreliable deadlines | |
| | | 38 | Lack of knowledge of the local market | |

**Table 3.** *Cont.*

| Category | Subcategory | Cause | | |
|---|---|---|---|---|
| Construction | Subcontractors | 39 | Lack of incentives for subcontractors to finish ahead of schedule | |
| | | 40 | Unavailability of adequate subcontractors | |
| | | 41 | Incorrect selection of subcontractors | |
| | | 42 | Technical and economic capacity or resources | |
| | | 43 | subcontractors change (descoping) | |
| | | 44 | subcontractors financial problems | |
| | | 45 | Low subcontractors productivity | |
| | | 46 | subcontractors pressure capacity | |
| | | 47 | Problems with the supply of construction materials: shortages, poor quality, high price, etc. | |
| | | 48 | Problems with the availability of machinery and equipment: shortage, slow mobilization, high price, etc. | |
| | | 49 | Late arrival of LLIs on site | |
| | | 50 | Problems with labor availability: absenteeism, strikes, shortages, low skills, slow mobilization, high salaries, problems in recruiting expatriates | |
| | | 51 | Accident rate | |
| | Location | 52 | Ground conditions are different from expected or contractual conditions | |
| | | 53 | Lack of availability of public services and infrastructure | |
| | | 54 | The project does not fit on the allocated plot of land | |
| | | 55 | Interference with other projects | |
| | | 56 | Delay in parcel delivery | |
| | | 57 | Loss of production time due to restricted access to the site | |
| | | 58 | Delay in delivery of approved for construction documentation | |
| | | 59 | Changes in the construction methodology | |
| | | 60 | Inadequate construction methods | |
| | | 61 | Poor or deficient construction supervision | |
| | | 62 | Inadequate planning and progress reporting | |
| | | 63 | Poor subcontractors coordination | |
| Handover | | 64 | Delay in inspection, testing or certification | |
| | | 65 | Delays in the provision of services by utility companies | |
| | | 66 | Unavailability of suppliers or services during startup | |
| | | 67 | Delay in the approval of completed work by the client | |
| Project management | Contractual | 68 | Inefficient contract management | * |
| | | 69 | Conflicts and legal disputes between participants | |
| | Non-availability of professionals in quantity and quality | 70 | Lack of personnel | |
| | | 71 | Lack of qualified personnel | |
| | | 72 | No clear definition of roles and responsibilities | |
| | | 73 | Changes in key personnel | |
| | | 74 | Organizational chart not adapted to the project's needs | |
| | | 75 | Delay in approvals/decision making | |
| | Project management team | 76 | Project management team without adequate experience | |
| | | 77 | Project management team without leadership | |
| | | 78 | Inadequate project control system (planning and cost) | |
| | | 79 | Optimistic planning or overestimation of productivity | |
| | | 80 | Incorrect cost estimate | |
| | | 81 | Delays in payment to suppliers and subcontractors | |
| | Poor communication | 82 | Poor communication between the client and the project team | |
| | | 83 | Poor communication between the project team and disciplines | |
| | | 84 | Poor document management | |
| | | 85 | Poor management of scope changes | |

**Table 3.** *Cont.*

| Category | Subcategory | | Cause | |
|---|---|---|---|---|
| Client | | 86 | Changes in scope | |
| | | 87 | Delay in progress payments or scope changes | |
| | | 88 | Unrealistic contract duration | |
| | | 89 | Slow approvals/decision-making; much bureaucracy | |
| | | 90 | Delay in site delivery | |
| | | 91 | Client or project management team (PMT) with little experience in similar projects | * |
| | | 92 | Representative without decision-making capacity | |
| External factors | | 93 | Inflation or price fluctuation | |
| | | 94 | Depreciation of local currency | |
| | | 95 | Regulatory changes | |
| | | 96 | Taxes, duties and customs duties | |
| | | 97 | Hostile political conditions | |
| | | 98 | Fraud and corruption | |
| | | 99 | Social instability | |
| | | 100 | Bureaucracy | |
| | | 101 | Effect of social and cultural factors | |
| | | 102 | Site characteristics (consider geomorphological, soils, hydrological and climatological effects) | |
| | | 103 | Environmental impact of the project | |

* Proposed by the authors.

**Table 4.** Measures to mitigate causes and cost overruns proposed in this work.

| Category | | Measure | |
|---|---|---|---|
| Preliminary phase | 1 | Solid front-end engineering design (FEED) | |
| | 2 | Scope of work and contract well defined in the bid package | |
| | 3 | Tenderers with the technical and economic capacity to execute the project | |
| | 4 | Accurate estimate of the total amount of investment required (at least class 3 according to AACE (Association for the Advancement of Cost Engineering)) | |
| | 5 | Realistic project execution planning without voluntarism | |
| | 6 | Guaranteed project financing that allows for predictable cash flow | |
| | 7 | Clear definition of interlocutors between the various stakeholders | |
| Engineering | 8 | Minimize design changes | |
| | 9 | Accelerate LLI (long lead item) equipment | |
| | 10 | Implement value engineering | |
| | 11 | Early incorporation of lessons learned from similar projects | * |
| | 12 | Assume no design data | |
| Procurement | 13 | Early awarding of LLIs (long lead items) and long lead time materials | |
| | 14 | Early incorporation of lessons learned from similar projects concerning vendors and suppliers | * |
| | 15 | Robust and updated list of vendors and suppliers | |
| | 16 | Continuous tracking of manufacturing and delivery schedules for key equipment and materials | |
| | 17 | Continuous monitoring of market trends (cost of raw materials and logistics, bottlenecks, etc.) | * |
| Construction | 18 | Periodic HSE (health, safety and environment) audits | |
| | 19 | Induction and periodic refresher HSE sessions | |
| | 20 | Early-stage outsourcing strategy | |
| | 21 | Technically and financially reliable subcontractors | |
| | 22 | Regular follow-up meetings with subcontractors | |
| | 23 | Early incorporation of lessons learned from similar projects concerning subcontractors | * |
| | 24 | Reliable and fast progress certification system, guaranteeing cash flow to the subcontractor | * |
| | 25 | Agile system for the incorporation of workers to the construction site | * |
| | 26 | Efficient work permit system that allows for safe work while ensuring adequate productivity | * |
| | 27 | Avoid early mobilization of the subcontractor to the site if no work front is available | * |

**Table 4.** *Cont.*

| Category | | Measure | |
|---|---|---|---|
| Handover | 28 | Robust fault detection and remediation system | * |
| | 29 | Conduct fault detection walks together with the client and only once per system | * |
| | 30 | Do not allow the client who closes the fault to differ from the one who detected/reported it | * |
| | 31 | Do not expect the client to accept unfinished systems | |
| | 32 | Lighten quality documentation required for acceptance of the installation by the client | * |
| Project management | 33 | Adequate transfer of information between the offer phase (commercial team) and execution (operations) | * |
| | 34 | Do not change key personnel | * |
| | 35 | Scope change system to the well-defined contract | |
| | 36 | Planning should anticipate problems, not just act as a logbook | |
| | 37 | Fast approval system | |
| | 38 | Efficient periodic project progress reporting system (planning and cost control) | |
| | 39 | Early assignment of the project control team | |
| | 40 | Clear definition of roles and responsibilities | |
| Client | 41 | Periodic meetings with the EPC contractor to review project progress and make decisions accordingly | |
| | 42 | Rapid decision making | |
| | 43 | Involvement of the end user from the beginning of the project | |
| | 44 | Sufficient experience in the type of project to be executed | * |
| | 45 | Do not request scope changes that impact the critical path | |
| External factors | 46 | Availability in the area of adequate resources to implement the project | |
| | 47 | Early community and stakeholder involvement | |
| | 48 | Solid economic study on the feasibility of the project | |
| | 49 | Regulation or legislation favorable to the project | |

* Proposed by the authors.

Table 3 lists the causes of delays and cost overruns that can significantly impact the development of an EPC project. In a novel way, they are structured into eight categories and 12 subcategories identified according the different execution phases of the temporal development of an EPC project. This structure can help improve the management and planning of this type of project by identifying, in advance, the leading causes of delays and cost overruns that could occur in each of the upcoming phases. On the other hand, the list of mitigation measures (Table 4) constitutes a set of best practices for project management. Additionally, the mitigation measures have been classified following the same category structure as the causes of delays and cost overruns, making it easier to identify problems (causes of delays and cost overruns) and their possible solutions (mitigation measures) in each of the phases of an EPC project. This information constitutes a tool for setting up a systematic development framework for establishing risk reduction plans for engineering companies that develop EPC projects.

## 4. Conclusions

The literature review carried out in this paper on delays and cost overruns in industrial EPC projects leads to the conclusion that, although there is extensive literature on delays and cost overruns in construction in general, few references (27) provide causes of delays and cost overruns and/or mitigation measures. Of these, only 10 categorize the causes and mitigation measures. Geographically, the Middle East, Europe and Asia account for 85% of the causes of delays and cost overruns. Few references prepared by professional or sectoral associations were identified, most of them being academic.

The bibliographic search initially provided 893 causes of delays and cost overruns and 147 mitigation measures, which after the filtering and selection process, were reduced to 103 causes of delays and cost overruns and 49 mitigation measures. These were grouped into eight categories based on the life cycle phases of an RGE project for a better understanding of them.

It has been identified that the categories of preliminary phase, construction and project management, all of them mainly dependent on the EPC company, are the ones that agglutinate a more significant number of causes of delays and cost overruns, while the causes dependent on the client's action are in the minority.

Therefore, the key aspects that cause delays and cost overruns during project management and the actions that can be implemented to avoid them were identified based on the literature review. The final classification of the significant causes and mitigation measures would allow for the future design of a systematic tool to be implemented in EPC project management to minimize delays and cost overruns. In this way, the economic viability and sustainability of these types of projects could be improved. Although this work is limited to EPC projects in the RGE sector, its general conclusions could be applied to any construction project and other industrial sectors.

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