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Investigation into the performance of oil and gas projects

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ABSTRACT

Many oil and gas projects experienced significant cost overruns, which is a major concern for the industry. The objective of this study is to investigate the cost performance of oil and gas projects by analyzing the data of approximately 200 public oil and gas projects. The average cost overrun of the projects is 18% with a standard deviation of 29%. The results also indicate that the error of underestimation is more frequent and greater than that of the overestimation. The projects' cost performance is also examined in terms of project size, type, region, joint venture information, and Final Investment Decision (FID) year. All effects of each factor are tested with statistical methods, and various drivers for cost performances are suggested to explain the differences in cost performance. The findings of this research will provide some guidance and references for future improvement in project performance.

1. Introduction and background

Average annual global oil & gas (O&G) project capital project investment is about US$1 trillion per year between 2011 and 2035 (IEA, 2011). However, the performances of the O&G projects did not get any attention until the recent oil price crashes. There are many metrics to evaluate project performance (e.g., cost, schedule, operability, and production). Cost performance is the key metric for determining whether a project is successful as cost is the aggregated outcome of all project scopes. Therefore, investigating the cost performance is a great approach for understanding the projects' performance. Few reports or papers have mentioned the performance of O&G megaprojects (greater than US$1 billion in cost). About 78% of the megaprojects have serious cost overruns and schedule slip (Merrow, 2012). EY (2014) reported similar findings with 64% of O&G megaprojects experiencing a cost overrun. More scholars have conducted research to investigate project performance in other industries. Pohl and Dubravko (1992) investigated more than 1000 projects from the 1940s–1980s and they had an average overrun of 21.5%. Flyvbjerg et al. (2004) found out that more than 250 public projects had an average overrun of more than 25%. Bertisen and Davis (2008) examined mining projects and found that about 13.5% of them went over budget. Bordat et al. (2004) reported more than half of Indiana public transportation projects had a 5% overrun. Kolltveit and Grønhaug (2004) concluded that Norwegian projects have experienced overruns ranging from 6% to 160%. Rui et al. (2011a, 2011b, and 2012a) investigated more than 200 compressor station projects and they had an average 11% cost overrun. Rui et al. (2012a, 2012b, and 2013) and Rui and Wang (2013) also found that the average cost overrun of 400 pipeline projects is 7%. Shehu et al. (2014) found a 2% average cost overrun for 359 Malaysian construction projects. Jacboy (2001) found that 74 projects had an average 25% cost overrun. Jahren and Ashe (1990) concluded that the naval facility project cost overruns were between −10% and 100%. Given the reported research, it can therefore be concluded that cost overruns are a global phenomenon and cost estimating error exists across many different types of projects. In addition to reporting the cost overruns, many researchers tried to identify their causes. Some authors reported that schedule delays are a key driver (Bordat et al., 2004). Others proposed that project teams were incentivized to develop low cost estimates in some cases (Flyvbjerg, 2014; Bertisen & Davis, 2008). Bordat et al. (2004) and Jahren and Ashe (1990) proposed that large projects have high complexity and there is a balance between competitive bidding and economies-of-scale for large projects. Merrow (2012) indicates that the quality of project Front-End-

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Loading drives project outcomes. Rui et al. (2012a, 2012b, and 2013) indicates that location, project size, and weather are factors affecting project performance. EY (2014) pointed out that internal factors (commercial context, project development, and project delivery) and external factors (regulatory challenges and geopolitical challenges) affect project performance. The performance of public-private-partnership (PPP) projects is more competitive than that for projects with traditional procurement; other studies indicated that PPP projects have worse performance than infrastructure projects using the typical procurement (Gleave, 2009). Flyvbjerg (2004) mentioned the effect of ownership on project performance and also explained the cost overrun issues using technical, psychological, and political-economic factors. Le-Hoai and Lee (2008) proposed that design issues, market issues, financial difficulty, and governmental regulations are drivers of cost overruns. Nawaz et al. (2013) found the drivers to be political interests, poor site management, corruptions, and change orders. Takim (2005) indicated that large contractors have worse performance, leading to cost overruns. Frimpong et al. (2003) determined the major factors affecting the performance of water projects, which included difficulties of monthly payments, procurement management, contractor issues, technical performance, and cost escalation. Sambasivan and Soon (2007) analyzed 150 surveys and identified major causes of schedule delays: poor contractor performance, finance and payment, labor supply, resource availability, lack of communication, dispute and litigation, and total abandonment. Ahsan and Gunawan (2010) investigated 100 projects and found that the major causes for the cost overruns to be the devaluation of local currency, bidding price, and large contingency budget. Kaliba et al. (2009) identified weather, scope changes, environmental protection, strikes, technical challenges, inflation, local governments, staffing, equipment unavailability, and poor management as major reasons for the cost escalation and schedule delay for Zambian projects.

The previous research on O&G project performance is very limited. This paper will try to explore O&G project performance with an in-depth analysis and provide some guidelines or references for project teams. The mission of an O&G project is to extract underground O&G for commercial use. Major process or steps for oil and gas projects include: locate the O&G, produce the O&G from underground, process the crude O&G, and transport it to a refinery or customer. O&G upstream and midstream projects are quite unique and specialized compared to other process projects or public transportation and building projects. O&G projects are relatively more capital intensive and natural resource based. Due to various process steps, an O&G project involves a high number of scopes: reservoir mapping, well drilling and completion, production facility building, and transportation system developing. An O&G project can be developed onshore, offshore, or via a combination of both. Therefore, the complexity of O&G projects tends to be high because of the numerous characteristics involved. Reducing project costs is now the first priority for all O&G companies. Understanding O&G project cost performance is critical for successfully implementing cost reductions or controlling current and future projects. Therefore, the objective of this paper is to investigate the performance of O&G projects and identify different drivers of the cost overruns.

2. Database and methodology

Project data are the foundation for quantifying the project performance and understanding the project outcomes and root causes. Scholars employed different ways to collect project performance data. Some researchers designed and distributed a survey to owner companies, contractors, and consultants for data collecting. The survey contained information regarding the project characteristics. The information includes project size, location, type of project, project sector, project nature, procurement types, tending methods, causes for cost overruns and delays, etc. (Le-Hoai and Lee, 2008; Shehu et al., 2014). Some scholars worked with large international organizations or government agencies to collect projects funded or supported by these organizations and governments. For example, Ahsan and Gunawan (2010) received data from 100 projects from Asian development banks and Pohl and Dubravko (1992) collected data from more than 1000 projects from the World Bank. Other groups of researchers collected project data by using public sources, such as publications, public databased, etc. For example, Rui, et al. (2011a, 2013) collected more than 200 U.S. pipeline projects and 400 compressor projects from O&G journals. The data for this study were collected from different public sources. Based predominantly on exclusive reviews of all literature and public sources regarding O&G project performance, data from 206 oil & gas projects were collected from the following major data sources: Business monitor international, the Global LNG Info website, the offshore technology website, the Subseaiq website, the quest offshore website, Oil & Gas journal, analyst reports from Thomson one, company websites and annual reports, and the Society of Petroleum Engineers. The project information was prepared on the basis of best-effort. The project data include the project cost, FID year, project types, location, company, joint venture (JV) information, etc.

The average project cost is US$765 million, with the individual project costs spread over a wide range from less than US$10 million to about US$9 billion. The average FID year is 2008, ranging from 2002 to 2013. The O&G projects in this sample are also well distributed around the world and all O&G production regions are included: 27% of the projects are from Europe, 23% are from Asia, 20% are from North America, 11% from Africa, 10% from Oceania, and 9% from South America. In addition, the project sample also includes all concepts in Industry, including fixed platforms, floating platforms, subsea systems, offshore wells, onshore wells, and onshore production facilities. In general, the Industry we observed was well represented in this project sample. The estimated costs are the approved project budget or cost at the FID gate for project development; the actual or final costs are the accumulated costs of the completed project. A cost overrun rate was used to evaluate the project cost performance. A positive rate indicates a cost overrun or underestimate and a negative rate indicates an underrun or overestimate.

To better understand the data pattern and differences among the groups, various statistical techniques are employed in this study for data analysis. A test was used with two sets of data to determine if they are significant different from each other. Each test will produce a p-value, which is used to determine whether the null hypothesis is true, and generally, a p-value less than 5% is considered to be a significant difference between two groups. The Mann-Whitney test (MW) determines if it is equally likely that a randomly selected value from one sample will be lower than or greater than a randomly selected value from a second sample. The MW also produces a p-value.

3. Findings

3.1. Overall cost performance

Cost performance provides great insight in understanding a project's performance and identifying the drivers. At the FID gate, the estimated project cost is one of the key factors affecting senior management's FID decision and the unexpected consequence of the overestimation or underestimation significantly influences the project outcomes. In some cases, poor estimations even lead to company financial difficulties due to large capital cost overruns. Therefore, cost performance is an important metric for evaluating O&G projects and companies.

As shown in Fig. 1, a relatively small number of cost overrun rates are narrowly spread around 0 and a large number of cost overrun rates are distributed far above 0. If the frequency of the overestimated cost is the same as the underestimated cost, the histogram would be symmetrical. Fig. 1 shows that cost overrun rates are widely spread and have non-symmetric distribution. More than 150 (74.0% of the total) projects were underestimated and 50 projects (25.0% of the total) were overestimated. The average cost overrun rate was 18.2%, which indicates that the average final cost of the collected projects was 18% higher than the estimated cost. The overrun cost was significant due to the project's large size. The overrun rates ranged from −32% to 169% with a large standard deviation (SD) of 29% and only 36% of the projects were completed within the −10% to 10% cost overrun range. The large range and SD imply that O&G project performance is very unstable and there are serious cost predictability issues as the performance is much worse than the expected accuracy range of −20% to 30% (AACE, 2016**)**. The high average cost overrun and large deviation indicate that reducing cost overruns and improving O&G project cost predictability are badly needed.

To understand the biased level and accuracy level of cost estimation for O&G projects, a binomial statistical test is used, which confirms whether the frequency of overestimated projects is equal to that of underestimated projects. The test results ($Pr < 0.01$) indicate that underestimating is more frequent than overestimating for O&G projects. Hence, the O&G project cost estimations are biased. The MW test results ($Pr < 0.01$) show that there is a higher magnitude of underestimating errors than overestimated errors. Therefore, O&G projects are more likely to have underestimating errors than i overestimating errors. This conclusion aligns with the findings from projects in other industries (Flyvbjerg et al., 2004). Flyvbjery et al. (2014) and Bertisen and Davis, (2008) suspected that project teams tend to underestimate project costs. EY (2014) also mentioned that project teams of megaprojects underestimated the risks associated the projects in the planning phase. Based on our observations and O&G project cost performance, O&G project estimators or project teams are also more likely to have aggressive target setting problems and optimistic bias issues. We also observed that many potential opportunities and projects in the portfolio channels are waiting for management approval, especially for large O&G companies. A similar observation from Pergler and Rasmussen (2014) indicates that a large number of projects or opportunities have different priorities in the portfolio, but the company has only enough capital to execute some of them. To compete with other projects or opportunities, many project teams or project managers are very likely to underestimate the cost by ignoring risk or hiding risk associated projects. This irresponsible action later on causes serious issues for project execution and on the outcomes. On the other hand, many project teams fail to recognize the project risks and complexity due to a lack of capacity and experience, which is very common for new technology projects or megaprojects. The data show that a high percentage of O&G projects cannot meet their planned goals because of the high cost overrun rate issue. Thus, fully understanding the drivers for project cost overestimating or underestimating will provide some useful guidance for improving project performance. Therefore, the more detailed analysis of project performance regarding the project characteristics is conducted in the following sections.

3.2. Cost performance in terms of project sizes

Project cost is used as a measurement of project size in this study. Many scholars have also mentioned that the size of projects affects cost overrun. Flyvbjerg et al. (2004) suggested that larger bridge and tunnel projects tend to have large cost overruns, but this is not found in road projects. Cantarelli et al. (2012) found that the cost overruns of road and fixed links decrease with project size, but the cost overruns of rail projects increase with project size. Rui et al. (2011a), Rui (2012c and 2012d) concluded that cost overruns of pipeline project total costs are affected by project size and large pipeline projects have large cost overruns, but not for individual component costs. Rui et al. (2013) also indicated that project size does not influence the cost performance of compressor station projects. Shehu et al. (2014) found that smaller Malaysia construction projects have larger cost overruns. Previous research literature indicated that project size has different degrees of effect on cost overruns in terms of the different types of projects. This section is to quantify the effect of project size on O&G project cost performance.

The O&G project size is much larger than that reported for projects in other industries (PWC, 2014). According to the

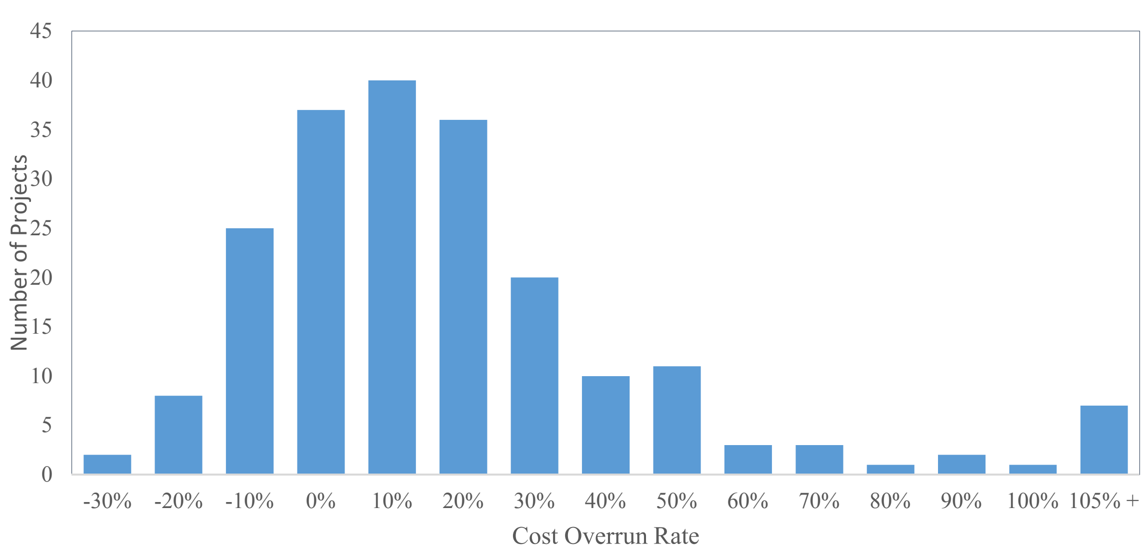

Fig. 1. Overall cost performance of the O&G projects collected.

distribution of estimated project costs, project is classified into three size groups. Small-sized projects are defined as those that cost less than US$200 million; medium-sized projects are defined as those between US$200 million and US$1 billion; and projects costing more than US$1 billion are defined as large size projects or megaprojects. In this study, each size project group has a decent number of representative projects: 80 projects in the small size project group with an average cost of US$104 million, 76 projects in the medium size project group with average cost of US$461 million, and 49 projects in the large project group with an average cost of US$2. 3 billion.

The cost performance for each project size group is shown in Table 1. The overrun rate is incrementally higher with the increasing project size, but the relationship between the overrun rate and project size is not straight linear. The cost overrun rates between the small and medium group are not significantly different ($Pr > 0.5$) with cost overrun rates of 15.5% and 14.6%, respectively. However, it clearly shows that megaprojects have the largest cost overrun rate of the three at 25.5% and the highest SD ($Pr < 0.01$). In summary, project size affects project cost performance and the performance for large projects is much worse than small and medium groups.

We try to explore some potential causes for large O&G project cost overruns in this section. With project size increasing, there is a higher possibility for a larger number of JV partners. The practice of a JV with multiple partners has become more common. However, as the number of partners grows, it becomes more and more difficult to align the objectives and secure funds from multiple partners. EY (2015) indicates that a JV takes about 18 months to establish and the failure rate of JVs is as high as 70%. In addition to the high number of partners, a large project often is a high profile project under pressure and being influenced by various parties around the project, such as non-governmental organizations, local residents, local governments, the federal government, etc. Typically, the period of planning and negotiation with different stakeholders will take 5 years or longer for large O&G projects. The effort and time to reach an agreement with local residents or local natives and receive permits from multi-government bodies or different countries are significantly higher for larger projects than smaller projects. One prime example is the purposed keystone XL pipeline project from the Canada to the United States, which took more than 10 years to be ultimately rejected by the U.S. government in November 2015. The difficulty and risk are even higher when dealing with unstable governments. Therefore, the associated cost of dealing with different stakeholders is hard to accurately estimate and forecast due to its high uncertainty. As is known, the mission of an O&G project is to extract O&G from subsurface. Since the first commercial well for production was drilled on August 28, 1859, a large amount of the easy oil from underground has been produced or is in production to meet global energy demand and the remaining undeveloped O&G reserves are becoming more difficult to be accessed and produced. To meet the growing world energy demand, O&G companies started to explore risker and more technically challenging regions with undeveloped natural resources, such as the Arctic regions, ultra-deep offshore fields, etc. They also developed a new technology for producing the O&G that previously was impossible to be commercially produced. The shale O&G development in North America using the new horizontal fracture technology and advanced stimulation methods is an example (Zhao et al., 2015a; Zhao et al., 2015b; He et al., 2016; Ren et al., 2016; Sun et al., 2016; Zhao et al., 2016). To justify the economics of producing difficult oil, more complicated large size O&G projects are being planned and developed and these projects tend to employ more new technologies and have a large number of sub-scopes. The new technology may increase operation efficiency in the future, but implementing the new technology application during initial development is not an easy task and will incur a higher cost and longer duration than a proven technology. Further, the supply of new technology is limited. For example, there are only three or four O&G service companies in the world that can provide subsea equipment and installation services. The lack of experienced teams and historical information on new technologies are common. Merrow et al. (1979) reported that new technology can add an extra 10%–20% of the total cost. Combinations of these factors make predicting the associated cost of implementing a new technology extremely difficult. Meanwhile, large projects often have a high number of sub-scopes with a high complexity due to their large capacity, complicated reservoirs, extreme weather conditions, etc. The high number of sub-scope increases the number of interfaces exponentially, and each additional interface increases the difficulty of integration, communication, project management, etc. Further, most large O&G fields are located in remote areas or developing countries (e.g., Africa). Unavailable or the lack of established infrastructure is a huge potential risk that can cause projects to not be completed within the proposed budget and time. This is because the companies have to spend extra time and cost to build the infrastructure for accessing the resources or transporting the produced O&G to clients. Megaprojects were also subject to labor issues and geopolitical challenges that are not common in relative small projects because megaprojects have substantial effects on society, the environment, and the government's fiscal revenue. Therefore, it is not surprising to see that large O&G projects experienced significantly higher cost overruns.

3.3. *Cost performance in terms of region*

Various O&G projects are developed in different regions to extract natural resources. The characteristics of the O&G projects in these different regions vary greatly, so the geographical region may be affecting project performance. Some researchers have already looked at the effect of the region on project performance. Flyvbjerg (2014) indicates that Dutch projects perform better with lower cost overruns compared to other geographical locations and suggested the geography factor should be taken into consideration. Olaniran et al. (2015) reported different megaproject cost overruns for projects in different regions, finding that different local or state governments may affect separated contract items. Cost performance is related to location because the technical requirements and Best Practices for engineering and installing offshore platforms vary in different regions (Hall and Delille, 2011). They indicated that pipeline project performances are significantly different for the different U.S. regions and proposed that weather, the surface

Table 1
Cost performance in terms of different project size groups.

Project size groups	Num. of projects	Average cost overrun	SD	Min	Max
Small Size Project	80	14.6%	28.8%	−28.0%	157.0%
Medium Size Project	76	15.4%	26.0%	−25.0%	109.0%
Large Size Project	49	25.5%	30.5%	−14.0%	169.0%

conditions, remoteness, and availability of supplies are variables for determining the regional difference (Rui et al., 2013; Zhao, 2000; Zhao and Rui, 2014). Very limited information is available on O&G project cost overruns across different regions from public sources. This section will demonstrate the cost performance for different regions and identify which regions perform better. In addition, the regional variation will be examined and possible causes for the overrun will be provided.

As seen in Table 2, each region has a good number of projects in the dataset. Europe has the largest share of the project sample at about 27%, followed by Asia with 23%, North America with 20%, Africa with 11%, Oceania with 10%, and South America with 9%. All O&G producing regions are included. It is obvious that the average cost overrun rate varies among the regions. The African projects average cost overruns of 35.3%, followed by South America at 21.0%, Oceania at 19.7%, Asia at 15.7%, North America at 15.6%, and Europe at 13.6%. The test results ($Pr < 0.01$) confirm that the average cost overruns vary across the different regions, and Europe and Africa are significantly different from the other groups in terms of the cost overrun rate. The African project cost performance has the largest SD, which is significantly higher than the other groups ($Pr < 0.01$). The high average cost overrun and SD imply that African projects have serious cost overrun issues and the poorest cost predictability. European projects have the lowest cost overruns and relatively small SD, which indicates that European projects are much better controlled than those in other regionals. Therefore, more investigation on projects from Europe and Africa will provide more valuable information to better understand the performance drivers.

Projects in Europe have the lowest cost overrun rate, and the cost of living in Europe is relatively high. The cost performance of European projects indicate that the cost of living-related factors may not significantly influence the high cost overrun rate, and that other factors may be more influential. The data limitations and lack of experience for certain regions may result in a high cost overrun. Some scholars (Flyvbjerg et al., 2004; Rui et al., 2011a; Cantarelli et al., 2012) proposed that the standard of professionalism and decision-marking system or culture of governance may also play role in project performance in different regions. Among all regions, Europe has the highest number of projects and most of them are located in the North Sea region as offshore projects. The concentration of European projects is much higher than that for other regions. Therefore, project teams in European regions gathered more practical experience, had a good understanding of the subsurface and surface situation, and had better access to the historical information. In addition, Europe generally has a high standard of professionalism and has produced a large amount of good engineers. These advantages make project performance in Europe very competitive.

The statistic test results also show that African projects have significantly higher cost overruns with most inconsistent performance compared to the other regions. The cost overrun rate is 10% higher than the global average overrun and more than two times the average cost overrun for European region projects. Industry has recognized the difficulty of implementing projects in Africa, and many factors have been found to drive the high cost overrun rate. PWC (2014) indicates that inadequate pre-engineering, weak project management, internal procurement, funding issues, governmental complications, and supply chains significantly affect African project performance. However, many drivers of the difficult development of O&G projects in Africa have not been very well identified and documented. In addition to the regular causes of cost overruns, there are still a few unique reasons or serious issues associated with African O&G project development (e.g., regulatory uncertainty and government stability). A World Bank report indicates that all African O&G production countries are the most difficult countries for doing business (World Bank Group, 2014). A good example is the local content policy. Local content, or the requirements for the O&G industry to generate more welfare or benefit to the local economy in addition to directly adding value, is a common policy in the O&G sector in Africa or other oil-producing regions (Tordo et al., 2013). The local content policy requirement is implemented to improve local employment, skill development, and local industry or company participation. O&G-producing countries have established various levels of local content requirements and most of them require a high percentage of local participation (Tordo et al., 2013). Africa is natural resource rich continent, and there are a huge amount of underground resources waiting to be developed. Most projects involve a large reserve and high complexity and are relative large. Therefore, almost all large O&G projects are developed by foreign O&G companies with a JV. According to the local content requirement, over 90% of the labor and technical professionals should be local residents and most equipment and fabrication should be supplied or done by local contractors (Tordo et al., 2013). Due to the high natural complexity and uncertainty of the projects, a significant amount of the goods and services are highly technological and specialized in nature. In reality, at present, African O&G-producing countries are incapable of providing adequate qualified local staff and contractors as required. Therefore, there is always a conflict between the local content requirement and local capacity in O&G project development in Africa. This conflict leads to unexpected schedule delays and cost overruns because more resources and time are needed to build the local capacity to complete the project. This situation worsens due to the frequent changes to these local requirements. It is a well-recognized fact that most Africa O&G-producing countries have serious government instability and diplomatic and security issues. These issues are critical for effectively implementing O&G projects, and the risks involved are very likely to add extra cost. All uncertain factors are summed up to significantly increase the difficulty of developing projects in Africa. Therefore, a set of Best Practices is greatly needed for improving O&G project performance in Africa. For example, more investigation work regarding the local region or government should be conducted to understand the true uncertainty and risk and prepare a contingency plan or assign a good amount of contingency in the cost estimate.

Therefore, it can be concluded that cost performance differs by region, and the different regions have common and unique factors that drive the cost performance, and these regional factors should

Table 2
Cost performance in terms of region.

Region	Num. of projects	Average cost overrun	SD	Min	Max
North America	41	15.6%	22.3%	−25.0%	94.0%
Europe	56	13.6%	25.4%	−32.0%	108.0%
Africa	23	35.3%	42.5%	−26.0%	152.0%
South America	19	21.0%	28.3%	−17.0%	169.0%
Oceania	21	19.7%	31.9%	−14.0%	132.0%
Asia	47	15.7%	31.3%	−28.0%	157.0%

be considered in the planning and estimation phase for O&G projects.

3.4. Cost performance in terms of the joint venture

With the increasing project size and complexity, the JV approach is widely used in the O&G industry to share risk and increase the capability between organizations or companies. The JV partners may include companies, government bodies, and/or financial institutions. A JV at a corporate level has been widely discussed and researched in the financial and management sectors. However, there is only a handful of literature on the JV project performance. Each company or organization has different objectives or reasons to pursue JV projects. EY (2015) listed eight major positive reasons for entering a JV partnership: capital intensity, risk mitigation, access to technology, access to resource, supply chain optimization, market position and scale, regulatory requirement, and political sensitivity. Meanwhile, the challenge incurred by the JV is also not easy to overcome and cost overruns of JV projects may be higher than in non-JV projects. The reports (EY, 2015) also mentioned seven major challenges regarding JV projects: the JV structure, alignment of goals and strategy, trusted relationship, integration, project leadership, timing of exit, and dispute resolution. All advantages and disadvantages aggregate to affect JV project performance as a whole. An investigation into project performance associated with JVs will help to identify drivers and establish Best Practices for ensuring JV projects are successful.

Just 19.5% of the projects are fully owned by one company. More than 80% were developed though a JV, meaning a JV is a common industry practice in the O&G industry for project development. This section tries to answer three questions regarding JVs. First, is the number of JV partners driven by project size? Because large projects tend to have s high capital requirement and complexity, large size projects are expected to have a high number of partners. Table 3 shows the number of JV partners ranges from 1 to 7 with the average number being 2.9. The average number of JV partners is almost the same between the small and medium size groups. However, large projects have an average of 3.5 JV partners, which is significantly higher than the other two groups ($Pr < 0.01$). This result confirms that as project size grows, so does the number of JV partners on O&G projects. The second question is whether the JV partnership affects the cost performance difference between JV projects and non-JV projects. As seen in Table 4, the average cost overrun rate for non-JV projects is 17.4%; for JV projects, it is 18.3%. In addition, the test ($Pr > 0.5$) shows that the cost differences between JV and non-JV projects is insignificant in terms of the average cost overrun and variance. Thus, it can be concluded that the JV type does not affect the cost overrun for an O&G project as a whole. The final question is whether the number of JV partners influences the cost overrun performance for JV projects. Table 5 shows that JVs with two or three partners are the most common JV format, accounting for 48 percent of the total. However, there are still a good amount of projects in the other groups. The cost overrun rate varies in terms of the different number of JVs, and the differences are significant ($Pr < 0.05$). The average cost overruns among the five different groups range from 13.5% to 25.7%. Projects with two JV partner have an average cost overrun of 25.7% with an SD of 38%, which is significantly higher than the other groups ($Pr < 0.01$).

Table 3
Number of JV partners in terms of project size.

Cost group	Average num. of partners	SD	Min	Max
Small Size Project	2.7	1.6	1	6
Medium Size Project	2.8	1.6	1	6
Large Size Project	3.5	2.0	1	7
Overall	2.9	1.7	1	7

Table 4
Cost performance in terms of JV and non-JV.

JV forms	Num. of projects	Average cost overrun	SD	Min	Max
JV	170	18.3%	30.8%	−32%	169%
Non-JV	36	17.4%	25.5%	−28%	132%

In summary, the number of JV partners increases with project size. On average, the differences in the cost performance for JV and non-JV projects are insignificant, but the number of JV partners significantly affects the O&G project performance of JV projects and projects with two JV partners have significantly higher cost overruns. The mix of advantages and disadvantages in JV projects accumulate together to affect O&G project performance. Different factors associated with JV projects may affect the project's cost performance at different degrees or in different directions (e.g., partner type, equity share, etc.). The findings from the study are informative and valuable, but further research regarding JV projects will focus on quantifying the risk of the factors with more detailed information.

3.5. Cost performance in terms of company type

The petroleum industry is comprised of a wide diversity of companies of a different size and type. Most large O&G reserves or producing countries have national oil companies (NOC), which are either fully owned or partially owned with majority shares held by the federal or local governments. An example is Saudi Aramco, the largest NOC in the world. About 75% of the world's oil production and 90% of the proved reserves are dominated by NOCs (Tordo, 2011). The general impression around NOCs is that they are characterized by operational inefficiencies and a lack of competition. Non-NOC O&G companies include international oil companies (IOC) and/or independent companies. IOCs are integrated upstream and downstream companies with worldwide operations. The top five major IOCs are ExxonMobil, Royal Dutch Shell, BP, Total, and Chevron. Independent companies normally are medium or small sized private or public O&G companies (e.g., Anadarko). The major difference between IOCs and independent oil companies are whether the companies have downstream sectors. In this study, all projects in this sample are upstream and midstream projects, so comparisons are made between NOC projects and non-NOC projects. Most NOC-developed projects are executed in the native country, but we have seen dramatic changes in recent years to NOC operations. Some NOCs are increasing their project investment outside of their native countries. Most current O&G projects have multiple JV partners and the partners can be different combinations of the different company types. We, therefore, defined a project as an NOC project if more than 50% of it was owned by the NOC; otherwise, it is considered a non-NOC project. Research also found some findings regarding the performance of public (government) owner and private owner projects. It is widely accepted that publicly owned projects are slow, costly, and of poor quality compared to privately owned projects. Hwang et al. (2010) conducted a study on the cost performance of publicly owned infrastructure projects compared to privately owned projects by analyzing the performance of 341 projects, and found that privately owned projects have a strong focus on cost control and profit. Flyvbjerg (2004) reported that there is a significant cost overrun difference between private and state-owned projects, but that the finding was not conclusive due to the small sample size. He also suspected that publicly owned projects lack the pressure and competition for

Table 5
Cost performance in terms of number of JV partners.

JV partners group	Num. of projects	Average cost overrun	SD	Min	Max
2 Partners	55	25.7%	37.7%	−23.0%	169.0%
3 Partners	44	17.1%	26.9%	−26.0%	109.0%
4 Partners	27	13.5%	24.0%	−14.0%	118.0%
5 Partners	22	14.7%	21.1%	−21.0%	93.0%
6 or more Partners	22	15.0%	20.3%	−18.0%	86.0%

improving performance and accountability. Regrettably, there is very limited information on project performance in terms of company type, aside from some general information regarding the corporate performance of NOCs and non-NOCs. NOC O&G projects differ from the above mentioned government projects because the major objective for NOC projects is the same as that for privately owned projects, maximizing profit and minimizing cost, whereas most government or publicly owned projects involve public interest and welfare, such as highways, hospitals, public facilities, etc.

As shown in Table 6, non-NOC projects, which account for 59% of the data sample, have an average cost overrun of 17.6%. NOC projects have a slightly higher overrun rate of 18.9%. However, the test results ($Pr > 0.5$) show that the effect of company type on the average cost overrun between non-NOC and NOC groups is insignificant. However, the SD test ($Pr < 0.05$) shows that the NOC SD of 0.33 is significantly larger than that for the non-NOC group of 0.28, meaning the performance of NOC projects is worse than that for non-NOC projects. Although the NOCs had widespread technology, project management, and other technical capability issues, they may also have some advantages: access to energy sources, local experience, social and economic development, etc. (Wainberg and Foss, 2007). NOCs in the OPEC groups perform better than their private sector competitors in terms of capital and labor efficiency and profitability (Wolf, 2008); NOCs outside the OPEC group are less competitive than their counterparts from the private sectors (Wolf, 2008). Our research shows that the cost performance difference is insignificant for different types of ownership, but the performance of NOC projects is less stable than that for non-NOC projects.

3.6. Cost overrun in terms of project type

Numerous O&G projects for different functions and sizes are developed around the world each year. All projects can be categorized into two groups: greenfield and brownfield. The greenfield projects are normally built on a new and undeveloped site; the brownfield projects refer to expansion or revamp projects on existing facilities. Both project types are common in the petroleum industry, and selecting greenfield or brownfield is determined by various factors. Greenfield and brownfield projects each have their own advantages and disadvantages. In general, the advantages of developing greenfield projects include no demolition, a flexible design, new regulation requirements, operation efficiencies, etc. The major disadvantages of greenfield projects include access to the site, lack of historical subsurface and surface data, lack of prior local experience, planning permit approval, etc. Many of the advantages and disadvantages of brownfield projects are that opposite of those related to greenfield projects. The advantages of brownfield projects include historical data, existing environmental or regulation approvals, existing infrastructure and facilities, prior local experience, etc. The disadvantages of brownfield projects include the limited design options, operation efficiency, difficulty of site operations, removing an unused existing facility, etc. Skitmore et al. (1990) found that refurbishment projects had higher cost overruns than new projects. The same was found for Malaysian construction projects (Shehu et al., 2014). However, there is no public information that shows that performance difference between greenfield and brownfield O&G projects.

In the data sample (see Table 7), 43% of the projects are brownfield projects and the rest are greenfield projects. Seen from Table 7 the average brownfield project cost overrun is 16.7% with a range from −32% to 152%. The greenfield projects have an average cost overrun of 18.1% with a range from −28% to 169%. The statistical tests ($Pr > 0.5$) indicate that the cost performance between the greenfield and brownfield groups is insignificant in terms of the average cost overrun and SD. Therefore, project type appears to have no significant effect on O&G project cost performance and neither greenfield nor brownfield projects are more prone to cost overruns. Minor quantified cost differences between greenfield and brownfield projects eliminate some concerns for companies to make decisions on using a greenfield or brownfield project.

3.7. Cost performance over the years

Some literature indicated that cost overruns have been common for years for different industries or different project types. Through an analysis of large transport projects in The Netherlands, Cantarelli et al. (2012) concluded that there is no relationship between year and cost overrun, and cost estimates do not improve over time. The cost overruns are stable for the 88-year period from 1910 to 1998 for more than 200 transportation projects in 14 countries worldwide (Flyvbjerg, 2014). In this study, O&G project performance is examined over time. With the help of new techniques and/or tools for estimation and advanced knowledge of projects, improved cost performance over time is expected. The year of FID is used as the year for measurement instead of the year of completion because the estimated cost is one of the major factors influencing the final decision on whether to proceed with the project (Flyvbjerg, 2014). Fig. 2 shows the cost overrun fluctuation over the years, but there is no clear trend over the years. The test results ($Pr > 0.1$) show that there is no significant difference between 2002 and 2013, which implies that new methods or new techniques for cost estimation are not leading factors that affect cost performance, which is in line with the observations from other scholars (Flyvbjerg, 2014;

Table 6
Cost performance in terms of company type.

Company type	Num. of projects	Average cost overrun	SD	Min	Max
NOC	84	18.9%	28.1%	−32.0%	169.0%
Non-NOC	122	17.6%	32.0%	−28.0%	157.0%

Table 7
Cost performance in terms of project type.

Project type	Num. of projects	Average cost overrun	SD	Min	Max
Brownfield Projects	88	16.7%	30.5%	−32.0%	152.0%
Greenfield Projects	118	18.1%	28.8%	−28.0%	169.0%

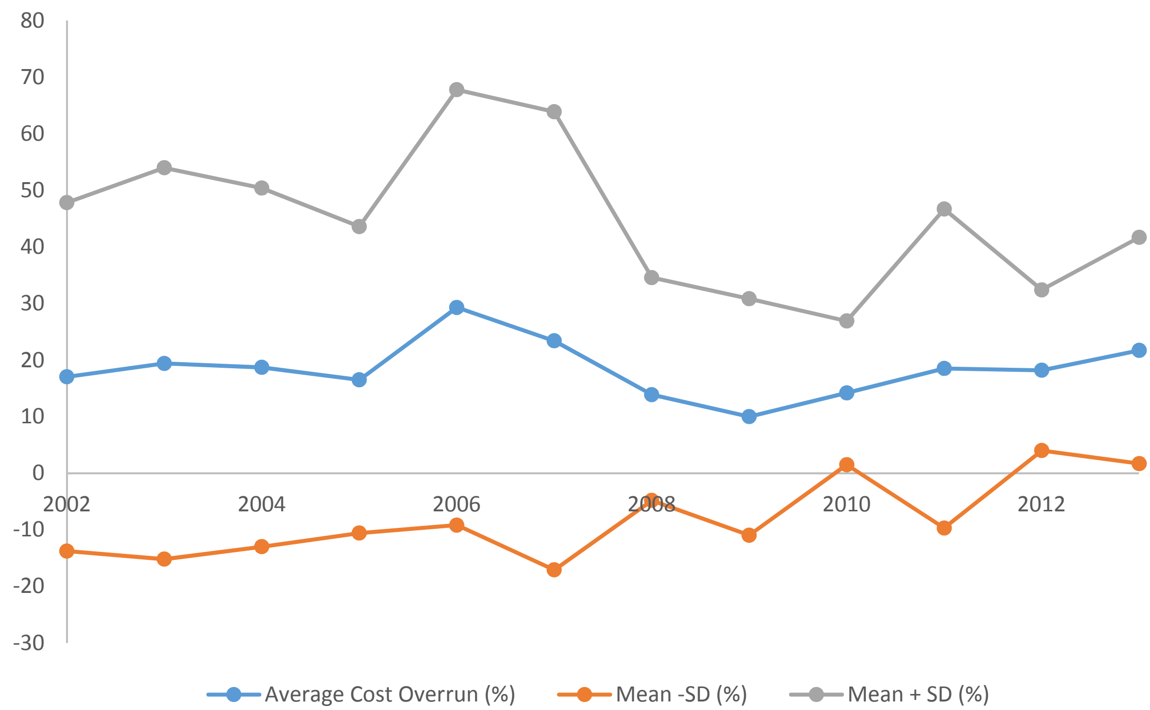

Fig. 2. Cost performance over years.

Cantarelli et al., 2012). New estimation or technical forecast tools were developed and applied over time. However, the O&G project's complexity and the associated risk also climb over the years due to O&G reserve's nature. Karev (2014) indicates that the increased reserve risk leads to a higher average risk profile for O&G megaprojects over the years because of increased capital spending on new cutting edge projects. In summary, cost overruns show some variations over the years, but the O&G project cost performance has not systemically improved over time.

4. Conclusion and suggestion

This study investigates O&G project cost performance in terms of project size, company type, JV, region, project type, and year. There are major findings as below: 1. The overall average cost overrun of O&G projects is 18% with an SD of 29%. The overruns for O&G projects are more frequent than underruns and the magnitude of overrun is also significantly higher than the magnitude of underrun. All findings indicate that the overall cost performance of O&G projects is worse than expected, implying that project teams fail to incorporate the risks in the planning phase. 2. The cost overruns for the large project group are significantly higher than that for the small size project group because large projects have more uncertainties. 3. The cost overrun rate varies across regions. European projects have the lowest cost overruns, but African projects have significantly higher cost overruns. Projects in each region have their own unique factors that affect cost performance. Learning experience, professional standards, the local content policy, the local capacity, and government stability were factors that potentially could be driving the regional difference. 4. The analysis of JV projects indicates that the number of JV partners increases with project size, but there is no statistical difference between the performance of JV projects and non-JV projects. However, the number of JV partners affects the cost performance for JV projects. 4. The difference between NOC and non-NOC project performance is insignificant in terms of the average cost overrun, but NOC project performance is worse because of larger variations in NOC project performance. 5. The performance differences between greenfield and brownfield projects are very minor. The cost performance varies over the years, but there appears to be no improvement over time.

The differences in cost overruns across the many different groups have been analyzed and tested, and potential causes or drivers for the underruns have been investigated or suggested; these findings will provide some insights into the cost estimators or project teams during planning. The project team should conduct a significant amount of preparation work to understand the project better and quantify the different risks related to the unique characteristics of each project. Then, different project risk settings or contingencies should be assigned based on project-specific situations to avoid cost overruns. Future work will include collecting more data and characteristics from projects that will allow us to use multi-factor methods to analyze the data to provide more meaningful insights around oil and gas project performance.

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