ANALYSIS OF KEY FACTORS TO IMPROVE MAINTENANCE MANAGEMENT IN
THE OIL & GAS INDUSTRY IN LATIN AMERICA

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ANALYSIS OF KEY FACTORS TO IMPROVE MAINTENANCE MANAGEMENT IN THE OIL & GAS INDUSTRY IN LATIN AMERICA

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ABSTRACT:
This article analyses the application of maintenance management (MM) in the oil and gas industry in Latin America. We conducted a web-based expert panel to develop a set of consensus activities that managers consider when managing maintenance projects. A heterogeneous group of 96 professionals related to maintenance tasks was selected to represent all the relevant perspectives (top management; maintenance; production; quality; logistics; and finance). Some 396 maintenance practitioners took part in a second online survey aimed at establishing the key MM factors that summarised the correlations among the previously defined maintenance activities. Moreover, an equation to discover the influence that these factors have in MM improvement was obtained. Finally, maintenance practitioners were classified into groups with similar MM styles according to previously defined MM factors. Results showed that three latent factors encompassed all MM activities: manpower efficiency; project management and IT; and asset performance optimization. Project management and IT was the most influential factor in MM improvement. Four groups were identified as representing different MM styles. The MM framework outlined in an inductive manner enables maintenance practitioners in the oil and gas industry to find out their strengths and weaknesses and plan their maintenance strategy accordingly. Moreover, the outlined procedure can be generalized for use in any industry.

Keywords: maintenance management; manpower; project management & IT; asset performance optimization

RESUMEN
En este artículo se analiza la gestión de mantenimiento (GM) en la industria del petróleo y gas en América Latina. Se realizó un panel de expertos online para obtener de forma consensuada el conjunto de actividades que se consideran en la gestión de proyectos de mantenimiento. Para ello se seleccionó un grupo heterogéneo de 96 profesionales relacionados con las tareas de mantenimiento para tener representados todos los puntos de vista relevantes (alta dirección, mantenimiento, producción, calidad, logística, y finanzas). Después, 396 profesionales involucrados en el mantenimiento participaron en una segunda encuesta online destinada a establecer desde el punto de vista de la industria los factores clave de la GM que resumen las correlaciones entre las actividades de mantenimiento previamente definidas. Por otra parte, se propone una ecuación para descubrir la influencia de estos factores en la mejora real de la GM. Por último, los profesionales de mantenimiento se clasificaron en grupos con estilos de GM similares según los factores previamente definidos. Los resultados mostraron que existen tres factores latentes que abarcan todas las actividades de la GM: eficiencia de la mano de obra; gestión de proyectos y TI y la optimización del rendimiento de los activos. La gestión de proyectos es el factor que más influye en la mejora real de la GM. Finalmente, se identificaron cuatro grupos como representantes de los diferentes estilos de la GM. El marco esbozado y la ecuación aportada de manera inductiva permiten a los profesionales del mantenimiento en la industria del petróleo y el gas conocer sus fortalezas y debilidades y planificar su estrategia de mantenimiento en consecuencia. Por otra parte, el procedimiento descrito se puede generalizar para su uso en cualquier otra industria.

Palabras Clave: Gestión del Mantenimiento, Mano de Obra, Gestión de Proyectos y TI, Gestión de Activos

1. INTRODUCTION

Maintenance is usually seen in organizations as a necessary cost that should be minimised and invisible. Maintenance costs can account for as much as 40% of the total operational budget [1]. So maintenance has traditionally been considered as a cost-centre or necessary evil that is normally relegated to a secondary level and has rarely been seen as a core business competency [2,3]. However, as the current economic crisis unfolded, companies focused more than ever

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on staying competitive with respect to cost, service quality, and punctual deliveries. In an increasingly competitive business environment, maintenance plays an important role as it can provide strategic market advantages in many ways – such as increasing capacity, reducing cost, and eliminating waste [4]. Moreover, the increasing adoption of JIT processes, TQM, lean manufacturing, agile and flexible manufacturing along with the growth of mechanization and automation make reliability and availability key factors when it comes to ensuring non-stop production [5]. This fact has become a major issue when the global crisis has forced companies to cut cost wherever possible. In this new scenario, it is crucial that maintenance evolves into an activity essential for account quality, cost, flexible delivery and customer satisfaction – becoming a proactive profit-focused activity that needs to be integrated within corporate strategy [6]. Thus implementing effective MM is crucial for organizations to ensure the timely delivery of goods and services in compliance with given requirements related to the personnel safety and risk posed to the public and environment.

However, it is difficult to find the right way to conceive and develop MM. Despite a considerable amount of theoretical work and general frameworks [2] [5-9] maintenance is a complex concern that creates many difficulties. Many authors have found a lack of effective MM models with a generally applicable operative methodology [9,10]. As theoretical applications with deductive approaches are difficult to implement it seems necessary to address MM improvement with an inductive approach. This article discusses the improvement of MM as part of a 'bottom-up' process, and involving maintenance practitioners who face barriers in implementing MM in their jobs (ranging from lack of top management support to lack of time to analyse, record, and control plant and process information). This paper analyses MM applications in the Latin American oil and gas industry from the viewpoint of professionals related to maintenance tasks (top management, maintenance, production, quality, logistics, and finance).

The aim of this study is to explore the significant gap that still exists in MM between theory and practice [11]. In this sense, the main objectives of the study are to discover the maintenance personnel point of view (planners, supervisors, and operators), set the underlying activities of MM considered in practice, correlate these activities and turn them into a small number of key MM factors. The initial hypothesis is that the resulting key MM factors will define a MM framework that will differ from previous MM frameworks devised using deductive approaches. In addition, this work attempts to estimate MM improvement in companies as a reflection of performance in key MM factors, and classify maintenance practitioners into groups according to their achieved performance in key MM factors. The idea behind this is that achieved performance on key MM factors among practitioners will allow classifying them in different groups with common MM patterns. These MM patterns could describe different MM styles, give a "big picture" of the maintenance organizational reality in this industry, and enable experts and academicians to establish the particular weaknesses to be managed in future works.

2. MATERIAL AND METHODS

The work was carried out in three phases:
1. Identification of the key factors for evaluating MM in practice.
2. Assessment of the relevance of the identified key factors in the improvement of MM.
3. Classification of maintenance practitioners into groups according to their current performance on the key MM factors.

2.1 IDENTIFICATION OF THE KEY FACTORS FOR EVALUATING MM IN PRACTICE

An international survey was performed using a web-based procedure to develop a set of consensus activities that managers normally consider when managing maintenance projects. A heterogeneous group of professionals related to maintenance tasks was selected in order to represent the perspectives of six working areas: top management; maintenance; production; quality; logistics; and finance.

The panel was selected so that panellist opinion could be determined and ensure an appropriate distribution across countries. A total of 96 people (10 from top management, 34 from maintenance, 17 from production, 12 from quality, 11 from logistics, and 12 from finance) agreed to participate from Venezuela (8%), Mexico (16%), Colombia (19%), Ecuador (15%), Brazil (16%), Peru (17%), and Bolivia (10%).

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The web-based survey consisted of the iterative process of managing the two rounds of surveys performed between November 2014 and January 2015. In the first survey, panellists were asked to provide a set of activities they perform or consider when managing maintenance tasks. A personalized e-mail was sent to each panel member with a URL link to the survey. The second round was devoted to classifying groups of similar activities that emerged in the first round. The participants debated the classification and then selected by consensus the most suitable activities to measure MM. The resulting items were the key activities resulting from the two-round survey in which each round was open for three weeks.

Once the key activities were identified, a web-based survey was designed to establish the performance level achieved for each activity by maintenance planners, maintenance supervisors, and operators. Some 36 plants belonging to 11 firms agreed to take part in the study. Specifically, only divisions devoted to oil production, refining and gas-LNG were analysed. Most of the firms operate in both production, refining and gas as shown in fig. 1. Some 396 professionals involved in maintenance tasks (19% planners, 29% supervisors and 52% operators) from oil & gas plants located in Venezuela (17%), Mexico (18%), Colombia (16%), Ecuador (12%), Brazil (15%), Peru (13%), and Bolivia (9%) took part in the study. All participants had a minimum of five years of experience and were randomly selected from databases of firms taking part in the study between Mars 2015 and September 2015. They completed an on-line questionnaire indicating their performance achievement for each of the maintenance activities detected in the previous expert panel, such as 'Setting the right size and composition of the maintenance team', using a performance rating scale from exceptional to unacceptable (5=exceptional; 4=exceeds expectations; 3=competent; 2=needs improvement; 1=unacceptable). The questionnaire also included an item about demonstrated maintenance improvement over the past three years ('Has your plant experienced a demonstrated improvement in MM over the last three years?') with 'yes' or 'no' being the possible answers.
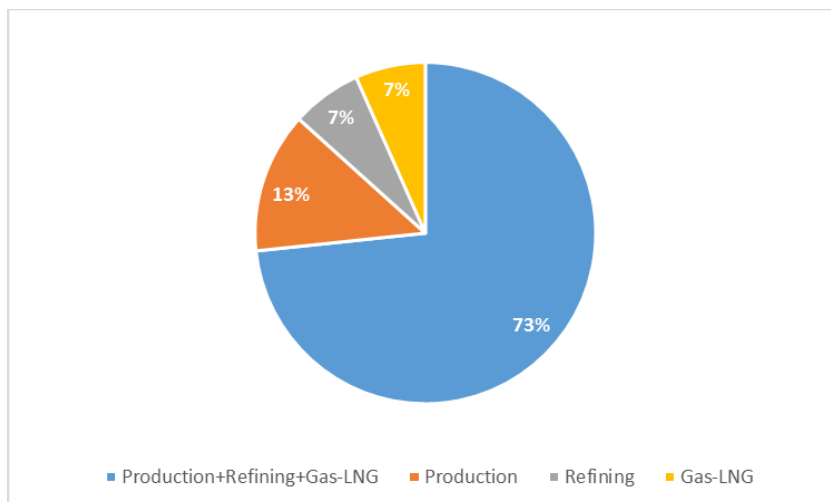

Figure 1. Distribution of firms devoted to oil production, refining and gas-LNG.

Data treatment consisted in a factorial analysis of the principal components with Varimax rotation to identify a set of independent factors explaining as much as possible of the variance (measuring MM performance according to MM activities resulting from the international web-based expert panel). The principal components were considered as the key factors to be considered by maintenance practitioners when evaluating MM.

The conditions set for the factorial analysis were:

1. (Kaiser-Meyer-Olkin Test) KMO >0.8
2. All eigenvalues had to be greater than 1 after rotation, i.e. any factor had to explain more variance than a single variable.
3. The communality of all variables should be greater than 0.6, meaning that information lost when working with factors should not be greater than 40% for any variable.
4. Components should be easy to interpret as MM dimensions.

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2.2. ASSESSMENT OF THE RELEVANCE OF THE IDENTIFIED FACTORS IN THE IMPROVEMENT OF MM

The key factors in MM identified in Section 2.1 were assessed by analysing their influence on maintenance practitioners' answers about MM improvement demonstrated over the past three years.

A binary logistic regression analysis was made with maintenance improvement as a dependent variable and factors scores of key MM factors as independent variables. This statistical procedure is widely used for developing equations that model the probability of one of two possible outcomes using a function of a set of predictor variables. The forward LR procedure was used. The Hosmer-Lemeshow test and the R^2 of Nagelkerke were used to assess goodness-of-fit and percentage of variance explained by the resulting equation respectively. Finally, the equation for probability of no maintenance improvement was obtained.

2.3. CLASSIFICATION OF MAINTENANCE PRACTITIONERS INTO GROUPS ACCORDING TO THEIR CURRENT PERFORMANCE ON KEY MM FACTORS

The goal of this analysis was to classify maintenance practitioners into groups with differing patterns regarding the MM factors identified in Section 2.1. To this end, a k-means cluster analysis was made to identify homogenous groups. Criteria employed to set that solution were: the maximum number of iterations until reaching convergence was set at 10; the minimum cases in each group in the final solution to be at least 10% of total cases; and final centres should be coherent and easy to interpret.

Each resulting cluster was considered as a style of MM resulting from different levels of performance achieved in each key MM factor. The maintenance style is described according to the mean values of the variables in the centre of the cluster. SPSS 16.0 in Windows was used for statistical analysis.

3. RESULTS

3.1. KEY FACTORS FOR EVALUATING MM

The panel response rates in the web-based survey responses were greater than 84% over the two survey rounds. The panellists taking part in the web-based study procedure selected seventeen different MM activities from the industry point of view, see Table 1.

Code	Maintenance Management Activity	Name in the Study
A1	Developing joint maintenance and production scheduling.	*Joint maintenance & production scheduling*
A2	Analysing asset investment and procurement	*Asset investment & procurement*
A3	Achieving effective integration and coordination between actors (operators, engineers, managers, suppliers and people in charge of outsourced maintenance tasks) belonging to maintenance related areas (production, logistics, quality and LCC, finance, RRHH, etc.) to reach maintenance goals	*Coordination of personnel involved in maintenance tasks*
A4	Managing spare parts and materials	*Spare parts & materials management*
A5	Educating and training operators in daily maintenance (inspections, adjustments, lubrication, etc.)	*Operator training*

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A6	Developing protocols (e.g. data collection, continuous quality improvement, cost-effective decision making) and organizing activities so that the safety and health of personnel, property, infrastructure and environment are not compromised	*Protocols development & activities organization*
A7	Calculating the manpower needed for maintenance activities	*Manpower calculation*
A8	Communicating effectively deviations in time, budget/cost, risk, quality, backlog and scope of maintenance activities	*Project monitoring*
A9	Defining and using the right maintenance performance indicators (MPI) to evaluate maintenance performance (based in EN13306, EN13460 and EN15341)	*MPI definition*
A10	Weighting the cost of maintenance, repair, or renewal versus the technical benefits	*Capital renewal*
A11	Measuring capacity and efficiency of assets	*Asset capacity & efficiency*
A12	Planning maintenance resources using CMMS (computerized MM system), MRO (maintenance, repair, and overhaul), EAM (enterprise asset management), or similar	*Maintenance resource planning*
A13	Achieving the right number and composition of maintenance staff	*Maintenance crew design*
A14	Achieving the right number of maintenance planners	*Number of planners*
A15	Achieving maintenance team members with technical expertise	*Staff technical expertise*
A16	Increasing profitability and translating maintenance performance into terms of economic impact	*Profitability & maintenance economic impact*
A17	Using project management standards (ICB – International Project Management Association, 2006), APMBoK (APM, 2006), PMBOK Guide (PMI, 2013), GAPPS Standards (GAPPS, 2007) for MM	*Use of project management standards*

Table 1. Maintenance Management Activities (the variable name used in the study shown in italics).

The results from the factorial analysis produced three principal components explaining 77.4% of total variance (see Table 2).

MM Activities	MM Principal Components		
	1	2	3
Staff Technical Expertise	0,815		
Number of Planners	0,778		
Maintenance Crew Design	0,741		
Manpower Calculation	0,727		
Operator Training	0,675		
Coordination of personnel involved in maintenance tasks	0,597		
Maintenance Resources Planning		0,834	
Joint Maintenance & Production Scheduling		0,813	
Project Monitoring		0,782	
Protocols Development & Activities Organization		0,762	

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MPIs Definition	0,711		
Use of Project Management Standards	0,689		
Assets Capacity & Efficiency			0,895
Asset Investment & Procurement			0,866
Profitability & Maintenance Economic Impact			0,751
Capital Renewal			0,687
Spare Parts & Material Management			0,601
Variance (%): 77.4	35,604	29,211	12,585

Table 2. Rotated factor matrix (coefficients lower than .5 have been removed for clarity). Total variance explained (%) and the contribution of each component is shown in the last row.

Factors are described using the maintenance activities that most correlate (R^2 into brackets) with components as follows:

Factor 1. Manpower efficiency (ME) referring to staff technical expertise (0.81), number of planners (0.78), maintenance crew design (0.74), manpower calculation (0.73), operators training (0.67), and coordination of personnel involved in maintenance tasks (0.60).

Factor 2. Project management & IT (PM&IT) related to maintenance resource planning (0.83), joint maintenance and production scheduling (0.81), project monitoring (0.78), protocols development & activities organization (0.76), MPIs definition (0.71), and use of project management standards (0.69).

Factor 3. Asset performance optimization (APO) considering asset capacity & efficiency (0.89), asset investment & procurement (0.87), profitability & maintenance economic impact (0.74), capital renewal (0.69), and spare parts & material management (0.60).

3.2. ASSESSMENT OF THE RELEVANCE OF THE IDENTIFIED KEY MM FACTORS IN THE IMPROVEMENT OF MM

Binary logistic regression analysis produces a model in which all three key factors are statistically significant. Fig. 2 shows the coefficients (B) as well as the odds ratio (Exp. B) for the significant variables, being the odds ratio the constant effect of an independent variable on the likelihood that no maintenance improvement will occur holding all other independent variables constant. Nagelkerke's R^2 is 0.68 and the Hosmer-Lemeshow test is not statistically significant (showing a good fit of the model).
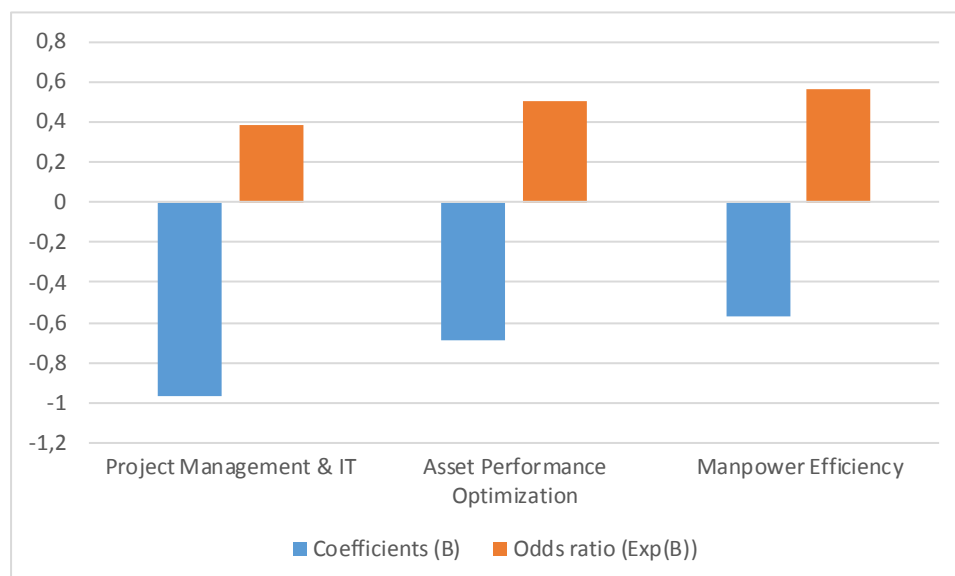

Figure 2. Effect of MM factors on the likelihood of No MM improvement.

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Results can be seen in Equation (1):

Prob. Of No Improv.$=1/(1+e(0.01+0.57 \times \text{Manpower}+0.97 \times \text{PM\&IT}+0.68 \times \text{Asset Performance Optimization}))$ (1)

3.3. CLASSIFICATION OF MAINTENANCE PRACTITIONERS INTO GROUPS ACCORDING TO THEIR MM STYLE

The k-means cluster analysis identified a valid solution for four groups. Fig. 3 shows the final centres of the groups. These groups are interpreted as four different styles of MM defined according to the importance of each variable. Fig. 4 shows the percentage of practitioners in each group.
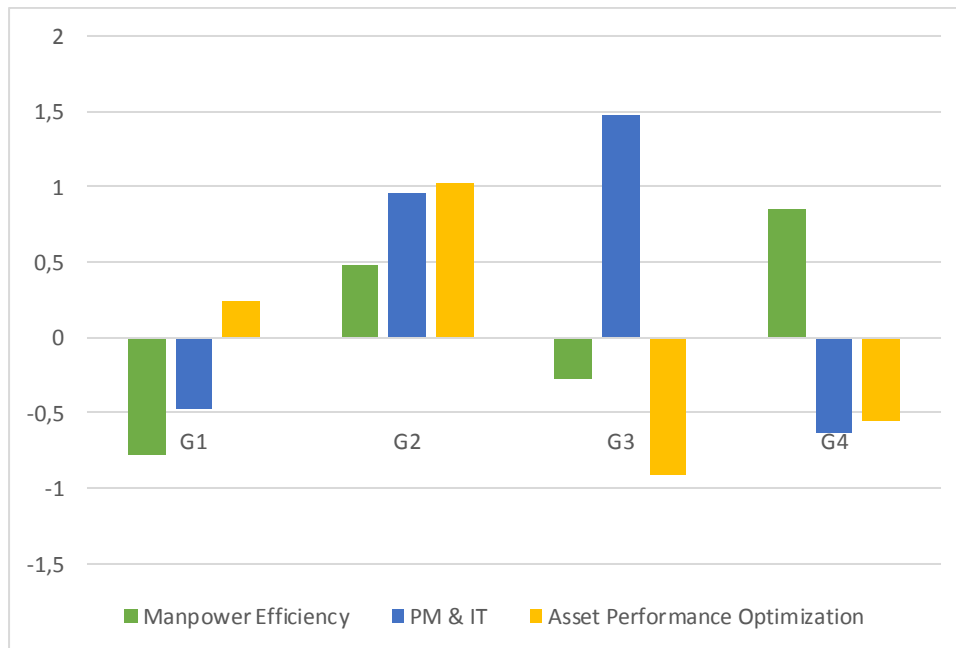

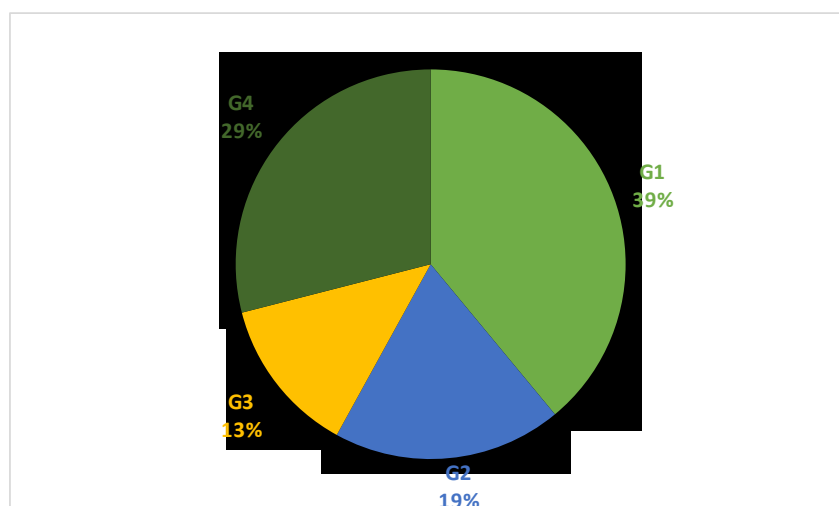*Figure 3. Final cluster centres of key MM factors in each group.*

Figure 4. Percentage of practitioners in each group.

The final groups of MM styles can be described as follows (see fig. 3):

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Group 1: This group refers to practitioners with the worst results in manpower efficiency and with high negative scores in project management standards; however, this group performs asset optimization acceptably.

Group 2: Practitioners belonging to this group are the best maintenance managers with high standards in all three maintenance factors. They have the highest value for asset performance optimization, and also have positive values for project management & IT and manpower efficiency.

Group 3: Practitioners in this group have the highest values in project management & IT; however, they have negative values in both manpower efficiency and asset performance optimization, reaching the worst value for asset performance optimization in all groups.

Group 4: Practitioners belonging to this group are the best in manpower efficiency, but the worst for project management & IT; and show a negative value for asset performance optimization.

4.- DISCUSION

This work has turned tacit knowledge of people related to maintenance into explicit knowledge. This fact is remarkable as the amount of tacit knowledge is high in the MM industry, leading to inefficiencies, lack of reliability and economical losses [12].

The web panel to set MM practices had a panel response rate of 84%, greater than the 70% established as an acceptable threshold to maintain rigor and avoid bias and lack of generalizability [13]. Regarding the online questionnaire, the achieved number of respondents slightly increased the sampling error initially planned (5%). Using Bromaghin's formula for interval estimation of multinomial probabilities [14], with $n=396$, $k=5$, $\sigma=1.96$ and the same sample portion value among response alternatives, the final sampling error is 6.4%. However, the final sample and distribution of maintenance practitioners among countries enabled us to make the planned statistical treatment of data, completing the research objectives with statistical significance in all performed analyses.

The key MM factors identified comprising the selected activities define a new MM framework. As a result, the starting hypothesis can be validated because, as far as authors know, the MM framework derived from practice differ from previous MM factors existing within theoretical frameworks. Only Manpower Efficiency was already considered as one pillar in the Crespo and Gupta's MM framework [7]. However, PM&IT and APO also emerge in this present study as key factors to improve MM in practice. PM&IT includes practices closely related to MM, as MM implementation is done by means of maintenance planning, control and supervision, and methods related to economic aspects of the organization [15]. In general, it could be said that practices such as planning, control and supervision appear in most maintenance theoretical frameworks scattered in the literature [5,6,16]. However, excluding the works of Duffuaa et al. [17] and Amendola et al. [18] who underline project administration as one of the main activities for keeping MM functional and productive, PM in itself has not received special attention. Finally, APO can be defined as the management of all assets owned by a company, based on maximizing the return on investment in the asset [2]. Over the last years, many authors have tried to assess the maintenance economic impact in business showing that maintenance can be seen as profit centre [7,9,19,20]. Moreover, the ISO 55000 family of European Standards published in 2014 has consolidated asset management as an emerging field which is growing in importance. However, asset management has not appeared as a pillar in previous MM frameworks.

In any case, resulting MM factors are in line with some previous studies which underline their importance in MM improvement. Ahmed [14] showed how increased manpower efficiency resulted in improved operations and cost saving in the Southern Area Oil Operations organization in the period 1983 to 2004. Papavinasam [15] pointed out that manpower has in practice still room for improvement in the oil and gas sector, as skilled operators are old and near retirement, and fewer people are entering the oil and gas business. Many experts [21] agree that demanding and highly competitive scenarios favour the introduction of PM as a formal methodology that goes beyond a specific application – and becoming an organizational ability that permeates the entire organization to achieve the intended strategic motivation. In this sense, Bardhan et al. [22] stated that IT solutions are crucial for sharing information among processes, mitigate the negative effect of team dispersion on project performance and contribute to a better interpretation of the financial side of MM. Finally, reality shows that maintenance systems have poor links to business

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and company strategy, leading to tactical and operational incongruence and inefficiency [23]. The solution of these issues are at the core of the asset management mission. Thus, MM in practice could be improved if managerial efforts were devoted to the improvement of the key MM factors identified in this study.

The results of binary logistic regression allow practitioners to evaluate the relevance of the identified factors in the improvement of MM. Companies could use equation 1 to improve their MM. They should: 1) rate their MM performance according to the key MM factors between -2 and 2, from "unacceptable" to "exceptional", 2) put the given values of each MM factor into the equation, and 3) calculate the resulting probability of improvement. This information could be used to set the starting baseline and to strategically establish which factors should be changed to improve the obtained probability. However, it is important to bear in mind that equation 1 has been obtained from questionnaires in an exploratory study. The equation's result therefore needs to be interpreted with caution. Maintenance performance reporting is difficult as it is time consuming and depends on the accuracy of the available data [24]. Moreover, the major benefits of improvements of maintenance are usually noticed in working areas such as production, quality, tied up capital, LCC management etc., but hardy registered in maintenance [19]. Thus, more control regarding the origins and causes of reported improvements and performances seems necessary in further studies.

The clustering analysis produced four types of MM styles. Excluding cluster 2 (19% of total practitioners), which had high positive values in all factors and excels in asset performance optimization, all the clusters had negative values in two out of the three MM factors and achieved the worst performance for one of them. Clusters 3 (13% of total practitioners) and 4 (29% of total practitioners) also excel in one out of the three factors, PM&IT and ME, respectively. This fact shows four different MM styles with extreme values that give us the idea that MM could be highly unbalanced. It is worth stating that we only registered the job function and expertise of maintenance practitioners. It seems necessary to discover more about the practitioner profiles as well as learning more about MM in every plant to gain a better understanding of MM styles. In this sense, the many dynamic factors in MM (such as age and quality of machinery, interpretations and use of maintenance concepts, environmental conditions, and technology) make interpretation of the study results among sectors very difficult. However, the procedure used from a bottom-up point of view can be generalised to provide insights into the critical MM success factors in any type of industry.

5. CONCLUSIONS

This study has identified the main MM activities that maintenance practitioners bear in mind when performing their job in the Latin American oil and gas industry. These activities are correlated and can be summarised by three principal factors differing from previous theoretical MM frameworks: manpower efficiency, project management and IT and asset performance optimization.

This paper has proposed an equation that predicts maintenance improvement as a function of the three MM factors previously identified. Project management and IT was the most influential factor for improving MM, followed by asset performance optimization and manpower efficiency. This information could help managers to establish the maintenance activities that need to be improved and plan their improvement strategy accordingly. However, with an exploratory study dealing with a complex concern as MM, caution must be applied, as the regression model using a limited number of variables could oversimplify the problem to be addressed.

Finally, the paper includes an assessment of practitioner performance according to their membership of different styles of MM. The MM styles are defined as a function of the key MM factors previously identified and four MM styles become apparent. This result shows the strengths and weakness of each group, giving a big picture of the state of the art of the MM performance sector and allowing researchers and practitioners to better plan their future works for MM improvement in this industry.

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