

# Performance of physical asset management using the analytic hierarchy process

Performance of  
PAM using  
the AHP

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## Abstract

**Purpose** – The purpose of this paper is to explore certain resources, capabilities and competencies needed to improve the performance of physical asset management (PAM).

**Design/methodology/approach** – The analytic hierarchy process (AHP) is used to select and prioritize the most appropriate factors for improving performance. A multi-criteria approach is used to analyze and compare the importance of 6 main criteria and 18 subcriteria identified from a survey of relevant literature.

**Findings** – The study revealed that not all factors are viewed as having equal importance in improving PAM performance, as three of the main factors attained greater importance among the six factors.

**Research limitations/implications** – This study explored the factors required for managing assets only within the third stage of asset lifecycle, that is, the utilization stage. It is recommended that future studies be conducted in such a way as to determine the importance of similar factors in the other stages of the asset lifecycle, or to identify new factors and add new criteria.

**Practical implications** – Knowledge of the differential impacts of the factors on the performance of PAM can impact asset managers and decision makers in their allocation of resources and focus their work on the highest-ranked rather than the lowest-ranked factors. Also, AHP used provides an effective mean for asset managers to identify priorities among decision criteria in their organization.

**Originality/value** – To date, no study has explored the impact of six combined factors on the performance of PAM. Previous studies have found that these factors each had equal importance. However, their relative ranking in practice and when they appear together have remained unrecognized.

**Keywords** Analytic hierarchy process (AHP), Assets, Firm performance, Assets management, Physical asset

**Paper type** Research paper

## 1. Introduction

Physical asset management (PAM) is a complex field, in which several activities and disciplines interact to plan and control asset lifecycle (Shah *et al.*, 2017). Organizations rely on assets as valuable elements which drive growth and enhance financial performance (Brennan and Mattice, 2013). In particular, physical assets are important items, which offer great tangible value to an organization (Teske, 2012). Also known as engineering assets, physical assets are defined as objects that have legal status and value. Some examples are land, equipment, machinery, buildings, vehicles, roads, pipes, wires, railways, aircraft, communication equipment and other infrastructure (Hastings, 2010; Mahmood *et al.*, 2014). This paper concentrates on PAM during operation.

Earlier, PAM was little used (Alfatih *et al.*, 2015); however, it recently has received increased attention, in particular after the publication of international standards like PAS 55 in 2004, and ISO 55000 in 2014 (Jooste and Vlok, 2015). As a result, Mardiasmo *et al.* (2012) found that firms have adopted an integrated and holistic approach to PAM to increase the performance of physical assets, reduce business risk and reduce the whole-life costs of assets (Mardiasmo *et al.*, 2012). Several studies have argued that efficient and effective delivery of services can be achieved if PAM is incorporated into operations (Hanis *et al.*, 2011; Parsa and Manase, 2014; Summerell, 2005). In the current, competitive business



environment, efficient PAM is crucial to obtaining the maximum return on the investment. But PAM requires the cooperation of various stakeholders from different departments, and each one has different interests, views and perspectives (Mahmood *et al.*, 2014).

To resolve the conflict between the several parties involved in managing physical assets, this paper describes a holistic study identifying six factors and describing their impact on PAM performance. To date, no study has explored the impact of six combined factors on the performance of PAM. Previous studies have found that these factors each had equal importance. However, their relative ranking in practice and when they merge into one framework have remained unrecognized. Additionally, previous studies have been conducted in the context of developed countries, such as Australia, New Zealand and the UK, and their focus has generally been on the private sector; this study, however, explores PAM in the context of governmental organizations in the United Arab Emirates (UAE). It:

- analyzes the factors needed to improve PAM performance in an organization;
- introduces a hierarchical framework to identify factors and their subfactors to improve the performance of PAM; and
- determines the prioritization for each factor and subfactor for performance improvement.

Asset managers require a framework that can enable them to consider complex problems in a simple way. The analytic hierarchy process (AHP) can be used to achieve that result at the same time as meeting the above objectives. This technique provides a framework to enable managers to make effective decisions on complex issues by simplifying and expediting decision-making processes. The data for this research are collected from experts working in governmental organizations in the UAE.

The remainder of this paper is organized as follows: the next section is a survey of the literature. Section 3 presents the research methodology, an overview of the AHP, its framework and the results. Section 4 offers a discussion of the findings. Section 5 contains the conclusion and the implications of the study, and finally, discusses the limitations of the study and suggestions of future directions for future studies.

## 2. Literature review

### 2.1 Introduction to PAM

Asset management is used in many firms and is a cost-effective approach to operating, maintaining and disposing of assets. More mature organizations treat PAM as a true investment, not just an expense (Schoeman and Vlok, 2014). Hastings (2010) defined PAM as: “a set of activities associated with identifying needed assets, funding requirements, ways of acquiring assets, provision of maintenance and logistic support systems for assets, and to dispose or renew them in order to meet desired goals effectively and efficiently.” El-Akruti and Dwight (2013) aligned their definition with asset management council definition as “The life cycle management of physical assets to achieve the stated outputs of the enterprise.” In general, PAM represents the systematic and coordinated actions and practices through which an organization optimally and sustainably manages its assets, asset systems, their associated performances, risks and expenditures over their lifecycles for the purpose of achieving its organizational strategic plan (Burnett and Vlok, 2014). Everywhere in the world, significant amounts of money are spent on managing assets in the multiple aspects such as: aging of assets, changing stakeholders and service-level requirements, health and safety requirements and the other requirements of regulating entities. The complexity of these factors has led firms to recognize how necessary it is to manage an organization’s assets and continuously enhance the performance of PAM by exploring the factors that go into developing a comprehensive improvement plan, and identifying the impact of these factors on overall performance (Parsa and Manase, 2014).

## 2.2 Factors affecting performance of PAM

It is vital to identify the factors by which the performance of physical assets can be improved and to prioritize them and their influence on overall firm performance. Managing assets involve several processes over the stages of asset lifecycle: creation, acquisition, installing, operations and maintenance, upgrade, renewal and disposal (Brennan and Mattice, 2013). According to Project Management Body of Knowledge, those processes are similar to the process of managing a project which consists of initiating, planning, executing, monitoring and closing (Kolar and Grozinik, 2017). Therefore, an asset management firm can measure its performance by adapting similar techniques used to evaluate the performance of project management. Project management performance is evaluated against objective factors such as cost, time, scope, quality, etc., as well as subjective factors characterized by perception such as customer satisfaction, project team satisfaction, etc. (Oun *et al.*, 2016).

Below is the list of the factors that affect performance of PAM.

**2.2.1 Resources.** Several authors have stressed the important role played by organizational employees to achieve the desired goals. Kriege *et al.* (2016) note that, while technical knowledge is important, human understanding is required to complete any given work. Human resources are a critical element in determining how well assets are managed.

Another critical resource is the inclusion of a technological element in asset management that improves strategies of communication and reporting. In reporting, the dynamic nature and fine details of the efficiency of PAM, in addition to asset depreciation and conditions, are accounted for in the final reports (Emmanouilidis *et al.*, 2009). On the other hand, during the lifecycle of an asset, the data and information on the asset continuously increase. However, emergent technologies, such as building information modeling, supports asset managers by complementing their strategic and tactical skills with the capacities required for data management (Roberts *et al.*, 2018). Moreover, built data and drawings of properties and physical assets can be updated to digital archives of information to facilitate asset management and future development (Sankaran *et al.*, 2018).

Asset management firms are restricted by their financial resources and their competitors in the global economy to maximize cost saving and increase profit. Generally, in asset management, two types of budget exist. They are the capital budget, CAPEX, which is associated with purchases of new fixed assets, and the operating budget, OPEX, which is responsible for operating and maintenance costs (Schuman and Brent, 2005). Vermiglio (2011) considered financial resources as one of the key variables to achieve an effective management approach for property management and real estate.

Overall, the three main sets of resources (human resources, technology and financial) overlap with, and influence, each other. Investment in new technology, for example, does cause a financial burden, but it results in improvements in work processes and requires training for the human resources to utilize the new technology. The typical company that has physical assets only has a limited budget to manage such assets (Schoeman and Vlok, 2014). Therefore, it is important for the organization to invest its funds wisely into developing human resources and implementing modern IT technologies to improve its PAM.

**2.2.2 Employee competencies.** The performance of PAM is influenced by, and dependent on, people and how they are managed. Moreover, the management of human competencies in organizations increases competitive advantage, innovation and effectiveness (Draganidis and Mentzas, 2006). Previous studies (Woodhouse, 2007) have indicated a lack of available methodologies and guidance for linking HR and technical business functions in improved people management. Several studies have found that this lack is a challenge for asset management, highlighting that the enhancement of the knowledge of human characteristics on the part of line managers will result in successful asset management. Moreover, it is important to be able to influence others, and good communication skills are essential for

supporting asset management (Swart *et al.*, 2016). Thus, it is necessary to identify how important employee competencies are in comparison with other factors.

**2.2.3 Practices.** Asset management involves systematic and coordinated actions and practices, through which an organization optimally and sustainably oversees its assets and asset systems (Alfatih *et al.*, 2015). Previous studies have described the importance of maintenance management in contributing to sustainable high performance of assets (Jooste and Page, 2004). Some of the maintenance strategies briefly introduced in this paper are preventive maintenance, corrective maintenance and predictive maintenance (Chandima and Markeset, 2010):

- Preventive maintenance is a helpful tool used to overcome issues that occur due to wear to assets. It is performed before asset failure and decreases the probability of potential failure and increases reliability (Chandima and Markeset, 2010; Fouladgar *et al.*, 2012).
- Corrective maintenance is also known as run-to-failure. It performs when failure occurs, and is considered to be a cost-saving strategy, but it might cause serious damages to assets, facilities, personnel and the environment (Chandima and Markeset, 2010; Fouladgar *et al.*, 2012).
- Predictive maintenance monitors the performance of the asset to predict when maintenance should be performed. This strategy offers cost savings over preventive maintenance, as well as allowing convenient scheduling of maintenance activities and preventing unexpected failures. It can be the most cost-effective approach to maintenance (Kirubakaran and Ilankumaran, 2016).

To achieve maintenance excellence, asset managers should correctly and efficiently plan maintenance activities. This is essential for the execution of PAM (Burnett and Vlok, 2014) and to maintain the value of the assets (Taylor, 2014).

**2.2.4 Partnership.** Changes in industry and technology are leading to greater opportunities for relationship-based and process-orientated asset management services. These changes include the following: shifting from periodic maintenance to whole-lifecycle management; adoption of ISO 5500 standards requirements; and evolutions in technology and computerized maintenance-management systems (Jooste and Vlok, 2015). Such changes make partnerships with service providers an inevitable requirement. Moreover, they can result in cutting costs, accessing new skills and more effective management of processes (Sanders *et al.*, 2007).

The most important factors that lead to professional partnership with service providers are: continued and sustained commitment from the senior management of the asset owner in support of the PAM service; open and effective communication between the asset owner and the service provider; and focused and continuous improvement processes to allow the PAM service to improve through monitoring, analysis and feedback (Jooste and Vlok, 2015). As service providers and asset owners partner to manage assets more efficiently, it is becoming more important to understand the importance of this factor in the success of PAM.

**2.2.5 Training.** Many scholars have emphasized the essential nature of training personnel in asset management (Hastings, 2010; Kriege *et al.*, 2016; Xerri *et al.*, 2013; Schoeman and Vlok, 2014). Asset management does not have any educational feed in; therefore, the management of competencies, training, development programs and knowledge play a key role in achieving strategies and goals. As part of a study conducted to highlight possible effects of risk management, forecasting and personnel training in PAM, it was suggested that 25 percent of the annual budget of each firm should be allocated to personnel training (Schoeman and Vlok, 2014). This recommendation shows the importance of training, and it is necessary to determine its relative priority in comparison with other factors.

**2.2.6 Workplace environment.** The effective development of processes to improve the performance of asset management requires an organizational culture that is encouraging and supportive. This kind of culture will facilitate and assist the organization in achieving its mission and goals (Xerri *et al.*, 2013). Studies such as that of Zuashkiani *et al.* (2011) highlight the vital role played by employees when collaborating with other teams within the organization and how it can result in ensuring effective asset management.

Table I presents a brief review of the literature related to the main criteria and subcriteria for improving the performance of PAM.

### 3. Research methodology

#### 3.1 Research context

Many governments worldwide acknowledge that future development plans depend on the management of physical resources. Many have also created plans bringing their citizens to 2020, 2030 or even later, with an agenda for future development, as Abu Dhabi has done. Abu Dhabi's 2030 vision focuses on uses of land to develop a professionally designed, sustainable and well-managed urban environment with a world-class infrastructure and transport system.

In the second quarter of 2018, Business Monitor International (2018) published a report about the infrastructure and construction industry in the UAE. The report considered UAE as an active real estate market and pointed that real estate markets in UAE have

| Main and subcriteria             | Description                                                                                                                                                                                            | References                                                                                                                                                                                             |
|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Resources                        | The three resources often overlap and have influence on each other                                                                                                                                     | Kriege <i>et al.</i> (2016), Emmanouilidis <i>et al.</i> (2009), Schoeman and Vlok (2014), Roberts <i>et al.</i> (2018), Phelps (2011), Sankaran Nevett <i>et al.</i> (2018), Schuman and Brent (2005) |
| Human resources                  |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Financial resources              |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| IT resources                     |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Employee competencies            | Human competencies in an organization increase its competitive advantage, innovation and effectiveness                                                                                                 | Kriege <i>et al.</i> (2016), Swart <i>et al.</i> (2016), Draganidis and Mentzas (2006), Woodhouse (2007)                                                                                               |
| Managerial skills                |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Technical skills                 |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Communication skills             |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Practices                        | Maintenance practices contribute to sustainably high performance of assets                                                                                                                             | Chandima and Markeset (2010), Fouladgar <i>et al.</i> (2012), Jooste and Page (2004), Kirubakaran and Ilangkumaran (2016), Burnett and Vlok (2014)                                                     |
| Preventive maintenance           |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Corrective maintenance           |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Predictive maintenance           |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Partnership                      | Changes in the industry and technology are leading to greater opportunities for partnership in asset management                                                                                        | Jooste and Vlok (2015), Sanders <i>et al.</i> (2007)                                                                                                                                                   |
| Commitment of asset owners       |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Open and effective communication |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Continuous improvement process   |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Training                         | Asset management has no educational feed in; therefore, management of competencies, training, development programs and knowledge play key roles in achieving strategies and goals for asset management | Hastings (2010), Kriege <i>et al.</i> (2016), Xerri <i>et al.</i> (2013), Schoeman and Vlok (2014)                                                                                                     |
| Technical training               |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Safety training                  |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Soft skills training             |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Workplace environment            | An encouraging and supportive organizational culture is needed to effectively improve the performance of asset management                                                                              | Xerri <i>et al.</i> (2013), Zuashkiani <i>et al.</i> (2011)                                                                                                                                            |
| Supportive managers              |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Good teamwork                    |                                                                                                                                                                                                        |                                                                                                                                                                                                        |
| Rewards and recognition          |                                                                                                                                                                                                        |                                                                                                                                                                                                        |

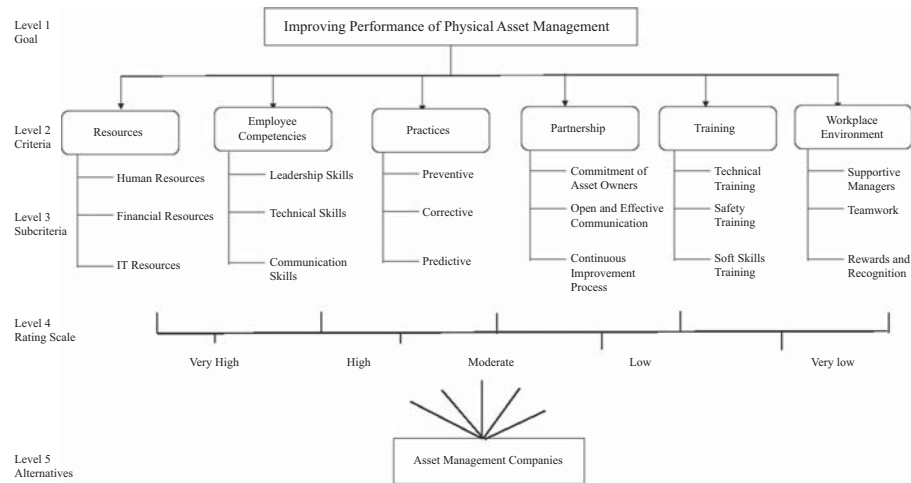
**Table I.**  
Criteria and  
subcriteria for  
improving the  
performance of PAM

returned to positive growth. The report forecasted GDP growth rate in the construction industry from 10.7 percent in 2017 up to 12.6 percent in 2027. The positive growth is due to the continuous government's support for the spending in infrastructure, transport and utilities which will provide construction growth opportunities and create new physical assets, such as buildings, roads, highways and infrastructure systems (Business Monitor International, 2018). Such assets would be vital for urban and regional development in the UAE, and they would retain high economic value. The efficient management of these assets will be essential.

3.2 Overview of AHP

The decision to improve the performance of PAM is a complex one, and multiple factors need to be explored, all of which are necessary to build a new strategy (Hussain and Malik, 2016). The importance of each could differ from one case to the next, and each decision maker could react differently to each factor. The AHP is often used to compare and identify the relative importance of each factor. It is a method developed by Saaty (2008) in 1980, and supports decision makers in focusing on most important matters. AHP is a powerful and flexible tool for handling both quantitative and qualitative factors. It involves expert opinion, and a small sample size is acceptable in its implementation (Nagi and Chan, 2005; Drake *et al.*, 2013; Al-Amor and Hussain, 2018). It consists of several steps which when applied properly can aid in solving complex problems with multiple criteria (Saaty, 2008).

Phase 1 involves structuring a hierarchy by breaking problems down into small elements. The first level describes the goal to be achieved, the second and third identify the main and subcriteria and the final one includes the different alternatives. The hierarchical structure for this study is shown in Figure 1. A list of 18 factors that influence the performance of PAM was generated from the studies summarized in Table I. The factors are integrated into six dimensions: resources, employee competencies, practices, partnership, training and workplace environment. With reference to content validity, the factors identified were approved by three experts in PAM who are working in different governmental organizations and academics in relevant fields. Some items required rewording to ensure they were representative of the intended constructs. This step allowed us to be confident about the validity of the proposed research framework.



**Figure 1.**  
AHP model for  
improving the  
performance of PAM

Phase 2 involved the construction of a pairwise comparison matrix of size  $(n \times n)$ , where  $(n)$  is the number of factors. The data in the matrix were obtained from the comparison of criteria by pairs by experts. Those comparisons were called judgments and were performed on using a nine-point scale, along 1 which represented the judgment that the two criteria in question contribute equally to the objective, and 9 meant that one criterion has absolute importance over the other criterion. The questionnaire (Appendix) was designed using the six factors identified for the improvement of the performance of PAM and using a nine-point scale, as described in Table II.

The target population consisted of personnel in managerial- or operational-level positions with roles and responsibilities that are greatly involved in the management of physical assets, such as head of asset management, facilities management directors, asset managers and chief and senior engineers. An approach to the target population took place at the Sixth Annual Government and Enterprise Asset Management Congress, held in Dubai in October 2017. More than 80 attendees from different companies attended, including 13 governmental organizations. In all, 30 experts were approached, and only 7, from five governmental entities, were willing to participate in the study. The participants had experience in asset management ranging between 10 and 23 years, an engineering educational background, responsible for large shares of governmental properties and assets and are working in positions such as director, asset management head/manager, chief engineer or senior engineer. The sample is aligned with the AHP method, which requires expert opinion and considers small sample sizes to be satisfactory. Face-to-face interviews were conducted by the researcher with the participants, and each interview lasted 30–45 min.

Phase 3 of the AHP checks consistency and develops the overall ranking of priority. A geometric mean approach is used to combine individual judgments of pairwise comparison and obtain consensus for pairwise comparison judgment matrices for the entire sample (Saaty, 2008). The consistency index (CI) is used for this purpose. Saaty (2008) defined the CI as follows:

$$CI = (\lambda_{\max} - n) / (n - 1),$$

where  $\lambda_{\max}$  is the maximum eigenvalue of the matrix of importance ratios and  $n$  is the size of the matrix or the number of factors. The consistency ratio (CR) is then used to evaluate whether a given matrix is consistent, by taking the ratio of CI to the random index (RI) value found in Table III. Random pairwise comparisons have been simulated to produce average random indices for different sized matrices. The table presents a list of RI estimated by Saaty (2008) for positive reciprocal matrices of orders 2–10 generated from the integer set 1–9 and their enforced reciprocals:

$$CR = CI / RI.$$

| Numerical rating | Verbal judgment                                |
|------------------|------------------------------------------------|
| 1                | Equally important/preferred                    |
| 2                | Equally to moderately important/preferred      |
| 3                | Moderately important/preferred                 |
| 4                | Moderately to strongly important/preferred     |
| 5                | Strongly important/preferred                   |
| 6                | Strongly to very strongly important/preferred  |
| 7                | Very strongly important/preferred              |
| 8                | Very strongly to extremely important/preferred |
| 9                | Extremely important/preferred                  |

**Table II.**  
Scale for AHP  
pairwise comparison

According to Saaty (2008), the CR is acceptable if it does not exceed 0.10. If it is greater, then the judgment matrix must be taken to be inconsistent, and the judgments should be reviewed and improved until a consistent matrix is obtained.

4. Analysis of the results

The experts were asked to evaluate the various criteria of AHP model by comparing the factors to each other two at a time (pairwise comparison), with respect to their impact on the main criteria in the hierarchy (AlJaberi *et al.*, 2018). In making the comparisons, the experts rely on concrete data available about the elements and use their judgments about the elements' relative meaning and importance. Based on the judgments made by the seven experts, a pairwise comparison matrix of the six main criteria (main AHP criteria) was established. Then the multiple judgments were synthesized by using their geometric mean. The geometric means of the pairwise comparisons for the six main criteria are presented in Table IV, and the rightmost column shows their relative priorities. The eigenvalue method is used to estimate the relative weights of the elements and their degree of importance. Relative weights are then integrated and synthesized for the final measurement of given decision alternatives and to determine priorities.

Table IV reveals that the resources factor was considered the most important element influencing the performance of PAM, with a vector priority weight of 40 percent, followed by employee competencies and practices, which had competitive priorities of 22 and 19 percent, respectively.

The three remaining factors, training, partnership and workplace environment, were ranked fourth, fifth and sixth, having less priority. The priority vector for Table IV shows that, together with resources, employee competencies and practices constitute more than 80 percent of the importance in improving the performance of PAM. It is also notable that the consensus responses in Table IV satisfy an acceptable CR.

To better understand the priorities reported and shown in Table IV, pairwise comparison of the subcriteria within the resource criteria was also undertaken, based on the respondents' consensus responses. Table V shows that the most significant element was found to be human resources (62 percent), followed by financial (30 percent) and IT resources (8 percent).

Table III.  
Random index

|          |      |      |      |      |      |      |      |      |      |      |
|----------|------|------|------|------|------|------|------|------|------|------|
| <i>n</i> | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
| RI       | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.48 |

**Note:** *n* is the number of factors

Table IV.  
Geometric means of  
pairwise comparisons  
of main criteria

|                          | Resources | Employee<br>competencies | Practices | Partnership | Training | Workplace<br>environment | Priority<br>vector |
|--------------------------|-----------|--------------------------|-----------|-------------|----------|--------------------------|--------------------|
| Resources                | 1.00      | 4.75                     | 2.75      | 5.00        | 3.75     | 6.25                     | 0.40               |
| Employee<br>competencies | 0.21      | 1.00                     | 3.50      | 4.25        | 3.00     | 3.75                     | 0.22               |
| Practices                | 0.36      | 0.29                     | 1.00      | 6.00        | 2.75     | 4.50                     | 0.19               |
| Training                 | 0.27      | 0.33                     | 0.36      | 0.57        | 1.00     | 3.50                     | 0.08               |
| Partnership              | 0.20      | 0.24                     | 0.17      | 1.00        | 1.75     | 2.00                     | 0.07               |
| Workplace<br>environment | 0.16      | 0.27                     | 0.22      | 0.50        | 0.29     | 1.00                     | 0.04               |

**Note:** CR value: 0.09 < 0.10 (consistent)

Similarly, among employee competencies, Table VI shows that the managerial skills were considered most important, with a priority score of 54 percent, followed by technical skills (31 percent). These two parameters together constitute almost 85 percent of total weighting for what could improve performance of physical assets on the basis of employee-competency criteria.

Likewise, among the practices subcriteria, the results in Table VII show that preventive maintenance practices were considered favorably relative to other practices, with a priority score of 65 percent, followed by corrective practices (25 percent), and predictive practices, with the lowest priority score (10 percent).

Table VIII also presents the geometric means and priority vectors of the remaining three subcriteria. The CR values clearly show that all results are consistent.

## 5. Discussion and conclusion

The results of this study suggest that the improvement of PAM performance is a complex process, influenced by the availability of adequate resources, employee competencies, application of good practices, partnership with external service providers and a supportive workplace environment.

Many key findings and contributions ensue from the AHP analysis, and they can be summarized as follows. First, the study revealed that not all factors are viewed as having equal importance in improving PAM performance, as was reported by previous studies and this finding is a novelty of study (Draganidis and Mentzas, 2006; Jooste and Vlok, 2015; Kriege *et al.*, 2016; Xerri *et al.*, 2013; Zuashkiani *et al.*, 2011).

Another contribution of this study is the clarification that the top three factors are resources, employee competencies and practices. The highest is resources, which is taken to

|                     | Human resources | Financial resources | IT resources | Priority vector |
|---------------------|-----------------|---------------------|--------------|-----------------|
| Human resources     | 1.00            | 2.75                | 6.25         | 0.62            |
| Financial resources | 0.36            | 1.00                | 5.25         | 0.30            |
| IT resources        | 0.16            | 0.19                | 1.00         | 0.08            |

**Note:** CR value:  $0.08 < 0.10$  (consistent)

**Table V.**  
Geometric means of  
pairwise comparisons  
of resources

|                      | Managerial skills | Technical skills | Communication skills | Priority vector |
|----------------------|-------------------|------------------|----------------------|-----------------|
| Managerial skills    | 0.55              | 0.62             | 0.44                 | 0.54            |
| Technical skills     | 0.25              | 0.27             | 0.40                 | 0.30            |
| Communication skills | 0.20              | 0.11             | 0.16                 | 0.16            |

**Note:** CR value:  $0.06 < 0.10$  (consistent)

**Table VI.**  
Geometric means of  
pairwise comparisons  
of employee  
competencies

|            | Preventive | Corrective | Predictive | Priority vector |
|------------|------------|------------|------------|-----------------|
| Preventive | 1.00       | 3.50       | 5.00       | 0.65            |
| Corrective | 0.29       | 1.00       | 3.25       | 0.25            |
| Predictive | 0.20       | 0.31       | 1.00       | 0.10            |

**Note:** CR value:  $0.08 < 0.10$  (consistent)

**Table VII.**  
Geometric means of  
pairwise comparisons  
of practices

**Table VIII.**  
Geometric means of  
pairwise comparison of  
partnership, training  
and workplace  
environment

|                                     | Commitment of<br>asset owners | Open and effective<br>communication | Continuous<br>improvement  | Priority vector |
|-------------------------------------|-------------------------------|-------------------------------------|----------------------------|-----------------|
| Commitment of asset<br>owners       | 1.00                          | 4.75                                | 4.25                       | 0.68            |
| Open and effective<br>communication | 0.21                          | 1.00                                | 1.75                       | 0.18            |
| Continuous<br>improvement           | 0.24                          | 0.57                                | 1.00                       | 0.14            |
| CR value: 0.05 < 0.10 (consistent)  |                               |                                     |                            |                 |
|                                     | Technical training            | Safety training                     | Soft skills<br>training    | Priority vector |
| Technical training                  | 1.00                          | 2.25                                | 4.00                       | 0.56            |
| Safety training                     | 0.44                          | 1.00                                | 4.25                       | 0.34            |
| Soft skills training                | 0.25                          | 0.24                                | 1.00                       | 0.10            |
| CR value: 0.08 < 0.10 (consistent)  |                               |                                     |                            |                 |
|                                     | Supportive<br>managers        | Good teamwork                       | Rewards and<br>recognition | Priority vector |
| Supportive managers                 | 1.00                          | 2.50                                | 5.00                       | 0.59            |
| Good teamwork                       | 0.40                          | 1.00                                | 4.75                       | 0.32            |
| Rewards and<br>recognition          | 0.20                          | 0.21                                | 1.00                       | 0.09            |
| CR value: 0.08 < 0.10 (consistent)  |                               |                                     |                            |                 |

have a significant influence on the improvement of the performance of PAM, and human resources is given the highest weighting in this category. This result supports previous studies which stated that the performance of asset management is influenced by and dependent on people, how they are managed and the understanding of human dimensional characteristics. Previous studies have also found that people are most fundamental to success in managing physical assets (Kriege *et al.*, 2016). They have emphasized that employees and leadership are equally as important as the PAM system itself (Schoeman and Vlok, 2014), and have shown that the human dimension determines the effectiveness and success of PAM.

The second-highest ranking is employee competencies. This result is also aligned with those of previous studies. For example, ISO 55000, adopted by the Institute of Asset Management, emphasized that “it is vital to remember that people ‘do’ asset management, therefore, people and their knowledge, competence, motivation and teamwork can make the biggest difference to good or poor asset management” (BSI, 2014). Moreover, managerial skills received the highest weighting among technical and communication skills. This outcome is to be expected, as previous studies have found that asset managers working in technical areas usually lack knowledge of HR practices and individual and dimensional human attributes. For this reason, it is critical to focus on managerial skills and overcome the challenges arising from ineffective management of human resources (Kriege *et al.*, 2016).

The third-highest ranking belongs to practices, a finding which supports previous studies as well. They have found that maintenance practices can have a critical impact on useful lifecycle and overall asset performance (Jooste and Page, 2004). The fact that preventative maintenance is the most significant practice in asset management confirms the results found by Fouladgar *et al.* (2012), who used AHP to choose the most suitable maintenance strategy for a mining company located in Iran. Five maintenance practices were compared, and preventative maintenance received the highest ranking of any other alternative.

Another study, conducted by Burnett and Vlok (2014) in a mining company located in South Africa, was performed to choose the most appropriate maintenance practices for different failure modes; it concluded that preventive maintenance was the preferred type for

the majority of failure modes, while predictive maintenance is the least preferred. Predictive maintenance is not to be preferred, because it requires highly skilled personnel to perform statistical analyses and detect the condition of the asset (Burnett and Vlok, 2014). Those capabilities are not equally developed everywhere, as found in previous studies, in fact, only a few countries, such as Australia, New Zealand and the UK, are considered advanced in this discipline (Phelps, 2011).

Furthermore, this study indicates that training, partnership and the workplace environment are among the least important factors for improving the performance of PAM. The finding contrasts with previous studies, which have emphasized that it is essential to train personnel in asset management (Hastings, 2010; Kriege *et al.*, 2016; Xerri *et al.*, 2013; Schoeman and Vlok, 2014). This discrepancy could have occurred because training is the first thing sacrificed by organizations when budget cuts occur (Zuashkiani *et al.*, 2011). Also, it was surprising to find that partnership has a lower priority, in contradiction of Jooste and Vlok (2015) who argued that asset owners and service providers must work in partnership during the different phases of the service lifecycle of asset management, and that it is important to select appropriate partners and have effective control and monitoring processes in place to continue to improve asset management service.

Furthermore, it was not expected to find that the workplace environment has the least importance of any criterion. Again, other studies have differed here, finding that positive workplace relationships improve employee attitudes and behaviors, which enhances organizational effectiveness and performance in asset management (Xerri *et al.*, 2013). This result suggests that the respondents in this study are satisfied with the work environments in their current organizations. Even though training and workplace environments received the lowest rankings of all factors, asset managers and decision makers should not neglect them as they develop their strategies or choose alternatives.

The final step in the AHP is to determine the ranking for the total 18 subcriteria (Hussain *et al.*, 2016). An overall relative priority for the 18 subcriteria was created as shown in Table IX. The relative priority was calculated by multiplying the subcriteria rankings by the criteria priority matrix. For example, the overall relative importance weight for the "Human Resources" was calculated by multiplying the weight of "Human Resources" by the weight of the main criteria "Resources" as  $0.62 \times 0.40 \times 100 = 24.80$ . Similarly, the overall

| Subcriteria                      | Overall priority | Ranking |
|----------------------------------|------------------|---------|
| Human resources                  | 24.80            | 1       |
| Preventive                       | 12.35            | 2       |
| Financial resources              | 12.00            | 3       |
| Managerial skills                | 11.88            | 4       |
| Technical skills                 | 6.82             | 5       |
| Commitment of assets owners      | 4.76             | 6       |
| Corrective                       | 4.75             | 7       |
| Technical training               | 4.45             | 8       |
| Communication skills             | 3.52             | 9       |
| IT resources                     | 3.20             | 10      |
| Safety training                  | 2.69             | 11      |
| Supportive managers              | 2.36             | 12      |
| Predictive                       | 1.90             | 13      |
| Good teamwork                    | 1.28             | 14      |
| Open and effective communication | 1.26             | 15      |
| Continuous improvement           | 0.91             | 16      |
| Soft skills training             | 0.86             | 17      |
| Rewards and recognition          | 0.36             | 18      |

**Table IX.**  
Overall priority  
ranking

relative weights were calculated for the other subcriteria as shown in Table IX. As per the results, human resources ranked the highest, at 24.8 percent, and human resources is part of resources, listed as the most important criterion. Preventive practices took second-highest rank, with an overall priority of 12.35 percent, and it is part of practices, which is ranked as the third most important criterion. The financial resources subcriterion was ranked at 12 percent, followed closely by managerial skills, with an overall priority of 11.88 percent. Consequently, a Pareto chart of the overall priority for the 18 subcriteria was developed as shown in Figure 2.

5.1 Implications

The findings of this study have theoretical and practical implication in areas that have not been sufficiently explored in previous studies. This study used the AHP to determine the importance of different factors for improving the performance of PAM, while previous ones have been limited to investigation of decision making for optimum maintenance strategies (Fouladgar *et al.*, 2012; Kirubakaran and Ilangkumaran, 2016; Ratnayake and Markeset, 2010).

The findings have significant practical implications. First, it is clear that not all factors are viewed as having equal importance for improving the performance of PAM, as reported in previous studies. Knowledge of the differential impacts of the factors on the performance of PAM can impact asset managers and decision makers in their allocation of resources and focus their work on the highest-ranked rather than the lowest-ranked factors. Focusing efforts on the highest-ranked factors will result in better performance and can help effectively position the organization as a leader among peer organizations in asset management. Furthermore, the AHP provides effective means for asset managers to identify priorities among decision criteria in their organization, which could also be generalizable to other industries. Moreover, since PAM has no educational feed in, the study will be beneficial for academics and for developing programs for asset managers.

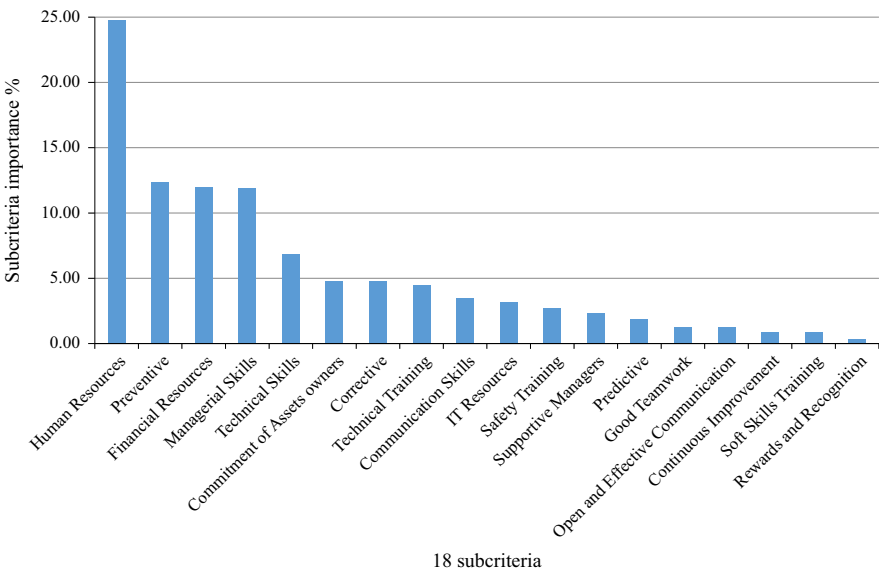


Figure 2.  
The overall priority of  
the 18 subcriteria

### 5.2 Limitations and prospects for future research

The following raises some limitations of the study. First, the current data were collected only from organizations based in the UAE, and the results can only be expected to be valid during the time period of data collection. Another limitation is that this study explored the factors required for managing assets only within the third stage of asset lifecycle, that is, the utilization or operation stage.

It is recommended that future studies be conducted in such a way as to determine the importance of similar factors in the other stages of the asset lifecycle, such as planning, designing, acquisition and disposal, or to identify new factors and add new criteria. A conceptual framework could be developed that would propose factors with the highest rankings as independent variables leading to the improved performance of PAM, with moderator agents such as the workplace environment. Several hypotheses can be proposed, and a structural equation model technique can be applied to test hypotheses and assess the consistency of the proposed model.

### 5.3 Conclusion

Techniques of PAM are used in many firms, and are considered to be cost effective for operating, maintaining and disposing of assets. Worldwide many governments accept that future development plans depend on management of physical resources. This study focuses on the determinants of decision-making processes to select the most appropriate factors needed to improve the performance of PAM. Such factors were not well identified and integrated in a single study, prompting this work to fill this gap. This study finds that factors are not in practice equal; therefore, the AHP is considered appropriate for determining the importance of different factors. This is a novelty of this study.

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### Further reading

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Appendix. Questionnaire

Please provide the following information:

Respondent Name (optional): \_\_\_\_\_

Age: \_\_\_\_\_

Gender (please circle): \* Male \* Female

Job title: \_\_\_\_\_

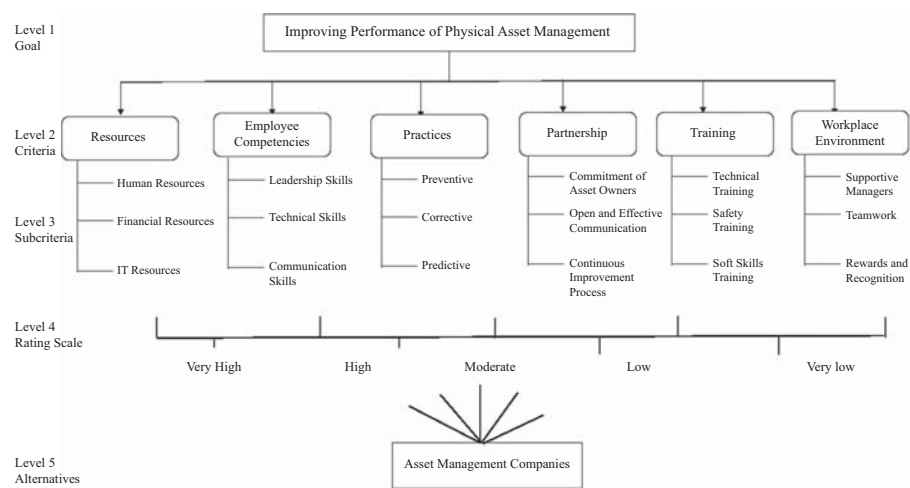
Organization name: \_\_\_\_\_

Department/division name: \_\_\_\_\_

Years of experience: \_\_\_\_\_

Highest educational degree obtained (please circle): \* High School \* Diploma \* Bachelor's \* Master's \* PhD

Email address: \_\_\_\_\_



## Performance of PAM using the AHP

[illegible]

| Resources             |                                  |                  |                           |                     |                          |                   |                        |                        |                              |                    |                                  |
|-----------------------|----------------------------------|------------------|---------------------------|---------------------|--------------------------|-------------------|------------------------|------------------------|------------------------------|--------------------|----------------------------------|
|                       |                                  | Equal importance | Weak or slight importance | Moderate importance | Moderate plus importance | Strong importance | Strong plus importance | Very strong importance | Very, very strong importance | Extreme importance |                                  |
|                       |                                  | 1                | 2                         | 3                   | 4                        | 5                 | 6                      | 7                      | 8                            | 9                  |                                  |
| Q1                    | Human resources                  |                  |                           |                     |                          |                   |                        |                        |                              |                    | Financial resources              |
| Q2                    | Human resources                  |                  |                           |                     |                          |                   |                        |                        |                              |                    | IT Resources                     |
| Q3                    | Financial resources              |                  |                           |                     |                          |                   |                        |                        |                              |                    | IT Resources                     |
| Employee Competencies |                                  |                  |                           |                     |                          |                   |                        |                        |                              |                    |                                  |
|                       |                                  | Equal importance | Weak or slight importance | Moderate importance | Moderate plus importance | Strong importance | Strong plus importance | Very strong importance | Very, very strong importance | Extreme importance |                                  |
|                       |                                  | 1                | 2                         | 3                   | 4                        | 5                 | 6                      | 7                      | 8                            | 9                  |                                  |
| Q1                    | Managerial skills                |                  |                           |                     |                          |                   |                        |                        |                              |                    | Technical skills                 |
| Q2                    | Managerial skills                |                  |                           |                     |                          |                   |                        |                        |                              |                    | Communications skills            |
| Q3                    | Technical skills                 |                  |                           |                     |                          |                   |                        |                        |                              |                    | Communications skills            |
| Practices             |                                  |                  |                           |                     |                          |                   |                        |                        |                              |                    |                                  |
|                       |                                  | Equal importance | Weak or slight importance | Moderate importance | Moderate plus importance | Strong importance | Strong plus importance | Very strong importance | Very, very strong importance | Extreme importance |                                  |
|                       |                                  | 1                | 2                         | 3                   | 4                        | 5                 | 6                      | 7                      | 8                            | 9                  |                                  |
| Q1                    | Preventive practices             |                  |                           |                     |                          |                   |                        |                        |                              |                    | Corrective practices             |
| Q2                    | Preventive practices             |                  |                           |                     |                          |                   |                        |                        |                              |                    | Predictive practices             |
| Q3                    | Corrective practices             |                  |                           |                     |                          |                   |                        |                        |                              |                    | Predictive practices             |
| Partnership           |                                  |                  |                           |                     |                          |                   |                        |                        |                              |                    |                                  |
|                       |                                  | Equal importance | Weak or slight importance | Moderate importance | Moderate plus importance | Strong importance | Strong plus importance | Very strong importance | Very, very strong importance | Extreme importance |                                  |
|                       |                                  | 1                | 2                         | 3                   | 4                        | 5                 | 6                      | 7                      | 8                            | 9                  |                                  |
| Q1                    | Commitment of asset owners       |                  |                           |                     |                          |                   |                        |                        |                              |                    | Open and effective communication |
| Q2                    | Commitment of asset owners       |                  |                           |                     |                          |                   |                        |                        |                              |                    | Continuous improvement Process   |
| Q3                    | Open and effective communication |                  |                           |                     |                          |                   |                        |                        |                              |                    | Continuous improvement process   |

| Training              |                        |                     |                                 |                        |                                |                      |                              |                              |                                    |                       |                            |
|-----------------------|------------------------|---------------------|---------------------------------|------------------------|--------------------------------|----------------------|------------------------------|------------------------------|------------------------------------|-----------------------|----------------------------|
|                       |                        | Equal<br>importance | Weak or<br>slight<br>importance | Moderate<br>importance | Moderate<br>plus<br>importance | Strong<br>importance | Strong<br>plus<br>importance | Very<br>strong<br>importance | Very, very<br>strong<br>importance | Extreme<br>importance |                            |
|                       |                        | 1                   | 2                               | 3                      | 4                              | 5                    | 6                            | 7                            | 8                                  | 9                     |                            |
| Q1                    | Technical training     |                     |                                 |                        |                                |                      |                              |                              |                                    |                       | Safety training            |
| Q2                    | Technical training     |                     |                                 |                        |                                |                      |                              |                              |                                    |                       | Soft-skills training       |
| Q3                    | Safety training        |                     |                                 |                        |                                |                      |                              |                              |                                    |                       | Soft skills                |
| Workplace Environment |                        |                     |                                 |                        |                                |                      |                              |                              |                                    |                       |                            |
|                       |                        | Equal<br>importance | Weak or<br>slight<br>importance | Moderate<br>importance | Moderate<br>plus<br>importance | Strong<br>importance | Strong<br>plus<br>importance | Very<br>strong<br>importance | Very, very<br>strong<br>importance | Extreme<br>importance |                            |
|                       |                        | 1                   | 2                               | 3                      | 4                              | 5                    | 6                            | 7                            | 8                                  | 9                     |                            |
| Q1                    | Supportive<br>managers |                     |                                 |                        |                                |                      |                              |                              |                                    |                       | Good teamwork              |
| Q2                    | Supportive<br>managers |                     |                                 |                        |                                |                      |                              |                              |                                    |                       | Rewards and<br>recognition |
| Q3                    | Good teamwork          |                     |                                 |                        |                                |                      |                              |                              |                                    |                       | Rewards and<br>recognition |

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