QATAR UNIVERSITY

COLLEGE OF ENGINEERING

EQUIPMENT CRITICALITY CLASSIFICATION USING ANALYTICAL HIERARCHY METHOD

BY

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A Thesis Submitted

to the Faculty of the College of

Engineering

in Partial Fulfillment

of the Requirements

for the Degree of

Masters of Science in Engineering Management

June 2018

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ABSTRACT

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Masters of Science in Engineering Management

Title: Equipment criticality classification using analytical hierarchy method

Supervisor of the Thesis: Mohamed Haouari.

The overall aim of this project is to use the analytical hierarchy process as new method in the equipment criticality process. The equipment criticality in the industrial sector is very essential part in the prioritizing process. All the equipment activities for maintenance or inspection will be based on the criticality of the equipment. Using AHP in the classification will allow to differentiate between the equipment that falls into the same ranking category.

The project starts with introduction chapter that explains the background of the AHP and about different applications uses the AHP process. The current practices in the industry, importance of prioritizing and the problem justification has been explained. A real case from gas company in Qatar has been utilized to apply AHP and to come up with criticality ranking. The result from the analysis was discussed in the last chapter.

DEDICATION

I dedicate my project to all my family who have never stop encouraging me during the challenges I faced. A special feeling of gratefulness to my parents, for supporting and encouraging me all the way until this stage.

ACKNOWLEDGMENTS

First, I would like to thank Prof. Mohamed Haouari for his continues support and direction to complete my thesis. Special appreciation for the college of engineering for their continuous support in the past two years in this master program.

I would like also to express my deepest appreciation to all those who provided me the possibility to complete this project. I would like also to thank all the participant from my company in the questioner that helped a lot to finish my research.

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CHAPTER 1: INTRODUCTION

In the industrial plants, the equipment criticality classification is an important factor that effect the reliability and the integrity of the operation facility. Equipment criticality is used to categorize the importance of the equipment and the associated risk with it. The ranking of the priority decided from knowing the consequence of failure. The consequence of failure needs a high-level meeting from operation, engineering, and process engineers in order to reach to the right priority.

Analytical hierarchy method has been widely used in order to prioritize list of activities. The uses of AHP method to prioritize the equipment criticality will be a very good way in order to distinguish between two equipment has the same criticality. In this chapter, the uses of AHP will be discussed in addition to the scope and the methodology that will be used to apply AHP in the equipment criticality case.

1.1 Background & literature review

In order to apply AHP in the equipment classification, it is important to understand the difficulties in applying the AHP in different applications. Furthermore, knowing the advantages and analyzing the result will be necessary to limit the expectations. In this section, some articles and studies of using AHP in different application will be analyzed.

1.1.1 Applying AHP to select drugs to be produced through anticipation in a chemotherapy compounding unit

AHP can be used to enhance the articulation of the appropriate criteria as well as to better describe organizational processes of licensing applicants' selection within pharmaceutical sector which was an extremely complicated problem as patientprotected products are to sustain the profitability and growth of the corporation. Another credible use of AHP is improving the selection of contagious medical waste disposal (Vidal, Sahin, Martelli & Berhoune, 2010).

The AHP involves a multi-criteria decision making technique and used to permit alternatives prioritization. The AHP is centered on the utilization of pairwise comparison that results in the explanation of a ratio scale. Additionally, the AHP enable to refine the process of decision making whereas analyzing the global consistency of the preferences of the user, because it may incorporate the calculation of overall consistency ratios (Vidal et al., 2010). The AHP is rooted in a 4-level hierarchy as demonstrated in the figure below:

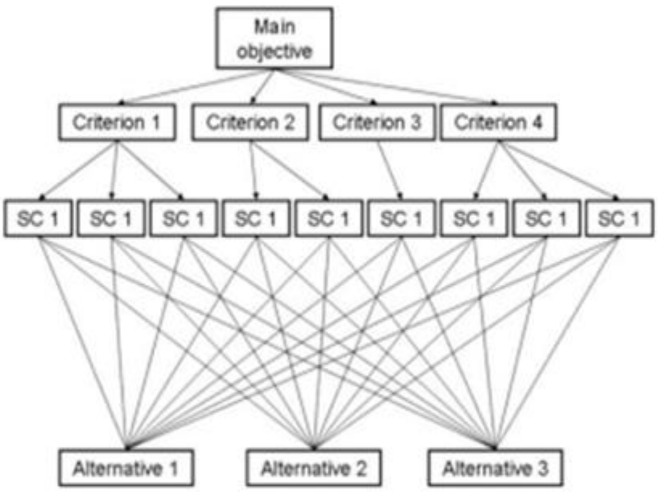

Figure 1: overall hierarchy structure of the AHP framework

The first step to develop the AHP is to produce a hierarchical framework of the problem. This would classify the decision criteria, variable, and goals into four main levels (Saaty, 2012). The greatest hierarchy level is the overall goal, such as identifying anti-cancer drugs to be developed through anticipation. Equally, level 2 signify the criteria as well as sub-criteria (Level 3) utilized to select the various drugs. Finally, level 4 is composed the decision alternatives (Vidal et al., 2010).

The International Common Denomination (DCI) acronym, which practically means chemotherapy drug name, has been broadly sued in the following study.

To determine the criteria and sub-criteria that the AHP would be centered on, interview would be done with pharmacists, mainly from UPIO and literature review. The selected criteria are then verified by other pharmacists from 3 additional hospitals. In the ending, the AHP framework criteria and sub-criteria are developed (Vidal et al., 2010).

Saaty scales were then elaborated for all criteria that were evaluated. Most of them, such as prescription time horizon, price, and stability required the skill of pharmacists to suitably describe them (Vidal et al., 2010). Therefore every Saaty scale differs from each other and corresponds to the particular case and veracity of every sub-criterion. After the AHP structure is completely constructed, calculi are then made. Initially, matrices have to be computed.

The entire project is to distribute the software to several anti-cancer drug manufacturing units in France, such units being independent for their individual expert judgments on the criterion within the AHP framework developed. The next section computes the software in this context in addition to testing and validation stages of the project (Vidal et al., 2010).

The entire methodology and AHP-based software was implemented during testing. The pharmacists collected data from field so as to do comparison verbally on each criteria and sub-criterion (Vidal et al., 2010).

Advantages of the Results

- The method allows for a comprehensive understanding of the issue and following a systematic technique in evaluating possible alternatives and support.
- It also enabled an integration of qualitative and quantitative data.
- Enables users to consider the preferences, experience, and personal judgment of the different players engaged in the research.
- Equally, the AHP model developed permits decision makers to compare diverse scenarios with regard to suitable criteria and thereby presents a real-time interactive as well as graphical demonstration of overall features. During the 5-month follow-up, majority of anticipated preparations (88-percent) were prescribed to patients at UPIU (Saaty, 2012).
- The follow-up confirmed that there were relevancy FabAct recommendations. The observation by pharmacists also validates that the cost of damaged anticipated preparations was negligible (0.4-percent of the overall cost of all preparations).

Disadvantages

- One of the disadvantage is that the criteria utilize in the evaluation may rapidly change as a result of new technologies and innovations employed in molecular research, thus require regular update (Ashraf, Richard & Glyn, 1998).

- Another issue is that the evaluation criteria also need to be further refined for analysis in this ever-shifting environment.

1.1.2 Evaluating Fisheries management options in Hawaii with analytic hierarchy process (AHP)

The AHP refers to a methodology to numerous criteria decision making designed by Thomas Saaty during 1970s. While not entirely based on utility theory the AHP practical nature has contributed to multiple different applications in the past twenty years to solve huge, complex, and indefinable decision problems. Consequently, AHP offers a simple and powerful analytical structure for the fishery management challenges at hand (Leung, Muraoka, Nakamoto & Pooley, 1998).

Steps in utilizing AHP to Address Decision Problems

- Establishing the decision hierarchy through disintegrating the decision problems into a hierarchy of interrelated organized decision elements, like a tree incorporating overall goal on top with several criteria levels and sub-criteria in between in addition to the alternatives at the bottom (Saaty, 2012).
- Gathering input data through pairwise comparisons of elements of the decision.
- Applying eigenvalue methodology in estimating the relative weight decision elements

- Lastly, aggregating the relative weight of decision elements in order to obtain a set of ratings for decision alternatives.

Advantages

- AHP enables gathering of any relevant element of decision making problems into a single model to work out their interdependence and their apparent consequences interactively (Ashraf et al., 1998).
- The user-friendliness and sophistication of Expert Choice software permits AHP uses to rapidly develop and tackle multiple criteria decision problem.
- The utilization of pairwise comparison makes AHP handlers to articulate the comparative relevance of the criteria and afterward to choose the relative importance of the alternatives to the employed criteria.
- The inconsistency measure enable AHP user to be informed of the significance of every inconsistent judgment.
- The hierarchical property of AHP enables simple and natural structuring of decision problems.

Disadvantages

- AHP users have to depend profoundly on their intuitive judgment and experience.
- AHP users do not always use the 7-very-stong-importance and the 9-extremely-importance scale as they do not view them to differ much with 5-strong-importance scale.

- Pairwise comparison eradicates the longer chains of interdependencies which many users recognize during evaluation of AHP (Saaty, 2012).
- There is need for a subjective starting reference point in pairwise comparison that could change a multiple criteria problem perception.

Steps in Developing AHP Tree

The management goals of the Pacific Regional Fishery Management Council (WPRFMC) can be identified using a 2-step approach, including:

- In the first step, a tentative list of management objectives/goals together with their definitions is compiled by integrating information from the interview of WPRFMC subcommittee's representatives with pelagic FMP. The tentative list was consequently included into a mail-out appraisal sent to chosen members of the Hawaii Council's Plan teams (PTs), pelagic, Scientific & Statistical Committee (SSC), and Council staffs for comments (Leung et al., 1998).
- In the second phase, the revised list of determined management goals and subgoals are then set up into a decision tree with the help of AHP. The first tree is tested and refined is then tested by a team of National Marine Fisheries Service (NMFS) researchers. The final framework of the decision structure is then forwarded to WPRFMC to give feedback during a council meeting (Leung et al., 1998).

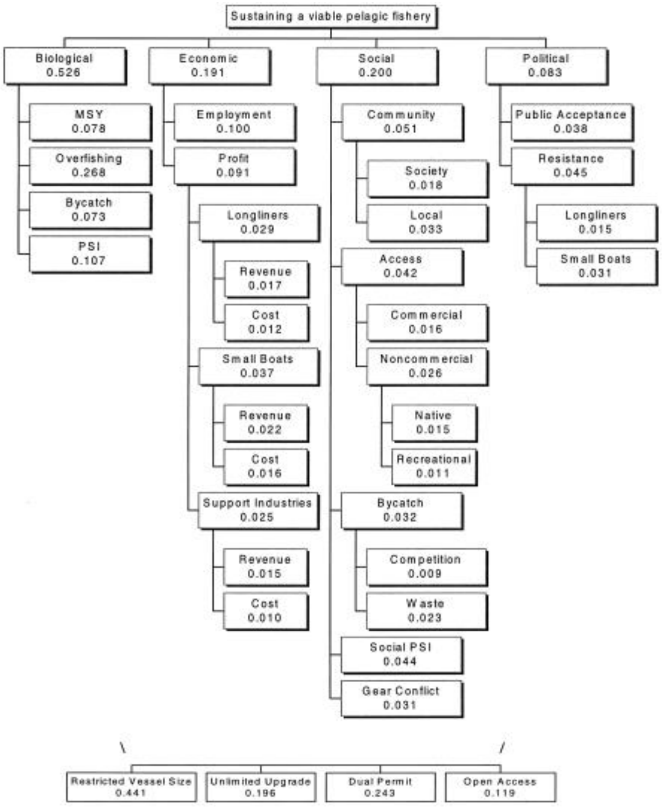

Figure 2:AHP tree - Hawaii pelagic fisheries management objectives (Leung et al., 1998, p. 176)

Results and Conclusion

The limited vessel size alternative contains the greatest priority for every potential weight of the all criteria used, therefore validating the robustness of the selected choice (Leung et al., 1998). In comparison with traditional decision making, the Analytic Hierarchical Process has the strengths of documentation, quantification, and timeliness (Saaty, 2012). AHP performed through mail surveys have high potential to serve as a decision-support mechanism for WPRFMC even though each decision-support system cannot substitute the actual decision making, especially in political choices. The present AHP tree structure in addition to the examined criteria and sub criteria priorities could readily be used in other decision circumstances faced by pelagic fishery of Hawaii. It can as well be adopted by other fisheries (Leung et al., 1998).

1.1.3 A decision support systems for supplier selection using an integrated AHP and linear programming

An integrated methodology for supplier selection in this case uses AHP, which utilizes pairwise comparison in order to make tradeoffs between intangible and tangible factors, calculate suppliers' ratings, and then apply these ratings as an objective function coefficients in linear programming, which distribute order qualities between the suppliers so that the total value of purchasing (TVP) turns maximum. Moreover, real quantitative data have been employed in AHP to enhance the consistency of the system and simplify the model calculation (Ghodsypour & O'Brien, 1998).

Steps of Algorithm:

Defining the Criteria for Suppliers Selection - Consistent with the integration of supplier-buyer, the organization's competitive state and corporate strategies, the important criteria for selecting supplier must be defined (Ghodsypour & et al., 1998).

Calculating the weights of the Criteria – After the structuring of hierarchy is completed, the weights of the criteria have to be calculated. The preferences between criteria would be requested from the top to the purchasing management by utilizing pairwise comparison.

Rating the Alternative Supplier (s) – The real quantitative obtainable data may be preserved for rating suppliers.

Computing the Overall Score of Every Supplier – The final score of every supplier is calculated by combining the supplier's rating and the weight of criteria. If there is no constraint, maximum score supplier is chosen and all demand is bought from this supplier (Ghodsypour & et al., 1998).

Building the Linear Model – If constraints like suppliers' quality and capacity exist, suppliers' ratings is used as coefficients of objective functions in linear programming so as to allocate order quantities to the supplier. Consequently, the TVP becomes maximum (Ghodsypour & et al., 1998). The supplier selection linear programming algorithm model is presented as follow:

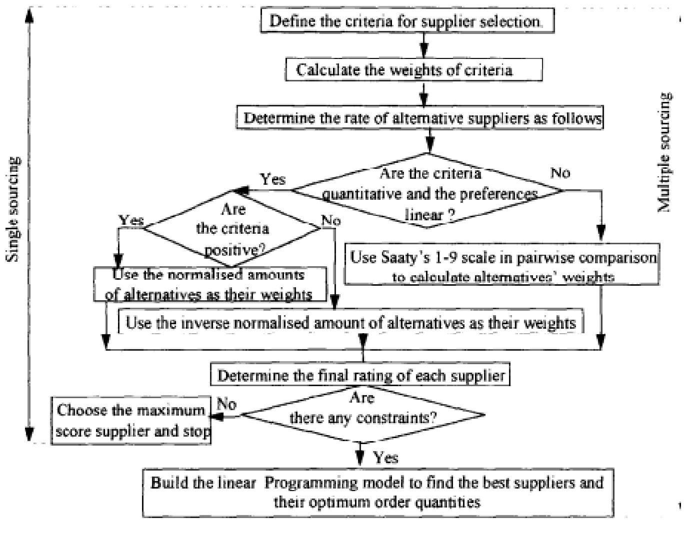

Figure 3:Supplier selection algorithm.

Results

Focusing more on supplier partnership increases the significance of suppliers' selection and raises the importance of taking into account quantitative factors in decision making process (Ashraf et al., 1998). A dynamic TVP establish an appropriate linkage between buyers' company policy and supplier selection. Order quantities are assigned to suppliers by this model in a way that the TVP becomes maximum with the help of linear programming and AHP. The management may also tradeoff between multiple tangible and intangible factors using various priorities through this model (Ghodsypour & et al., 1998).

1.1.4 The relocation of hybrid manufacturing/distribution facilities from supply chain perspective

AHP refers to a scoring technique designed to visually structure complex decision problems into a simplified hierarchy and then create priorities in each level of hierarchy through conducting simple pairwise comparisons of attributes, relative importance of each decision criterion, and alternatives (Min & Melachrinoudis, 1999). The application of AHP is appropriate for a relocation decision faced by Alpha for two primary reasons:

- AHP is an efficient tool for solving a relocation decision concerning multiple tangible (such as costs) and intangible (such as quality of living) factors of location with various scales.
- The presence of user-friendly features in AHP enables the relocation planners to visualize preferences from the relocation alternatives and to

identify contradictory judgments and rectify them in the course of decision process (Min et al., 1999).

To show how the AHP functions and to confirm its effectiveness, the model was employed to real-world problem faced by Alpha. These steps include the following:

- Alpha management team first identified potential industrial sites. These sites were screened using AHP-centered stratification scheme because simultaneous analysis of the ten diverse sites may need an undue number of pairwise comparisons and as a result overwhelm consistent judgment abilities of the location planner (Min et al., 1999). Some possible sites like Port Jervis, Easton, and as East Stroudsburg, for example, are adjacent to one another and have depicted typical location features in terms of local incentives, market opportunities, and traffic access (Ashraf et al., 1998).
- Following a sequence of pairwise comparisons using AHP, the most dominant sites in every state was identified.
- The final candidate list of sites selected for more consideration included (a) Harrisburg, Pennsylvania, (b) Williamsport, Maryland, and (c) Wheeling, in West Virginia.
- To complete a hierarchical demonstration of the relocation decision, 33 relocation factors were aggregated into six extensive relocation clusters (criteria) (Min et al., 1999).
- To verify the criteria, two simple rules were applied; (a) the specified location factors from similar criteria are homogenous (commensurate)

with each other and (b) the list criteria must be restricted to a considerably small number to facilitate reliable pairwise comparisons (Min et al., 1999).

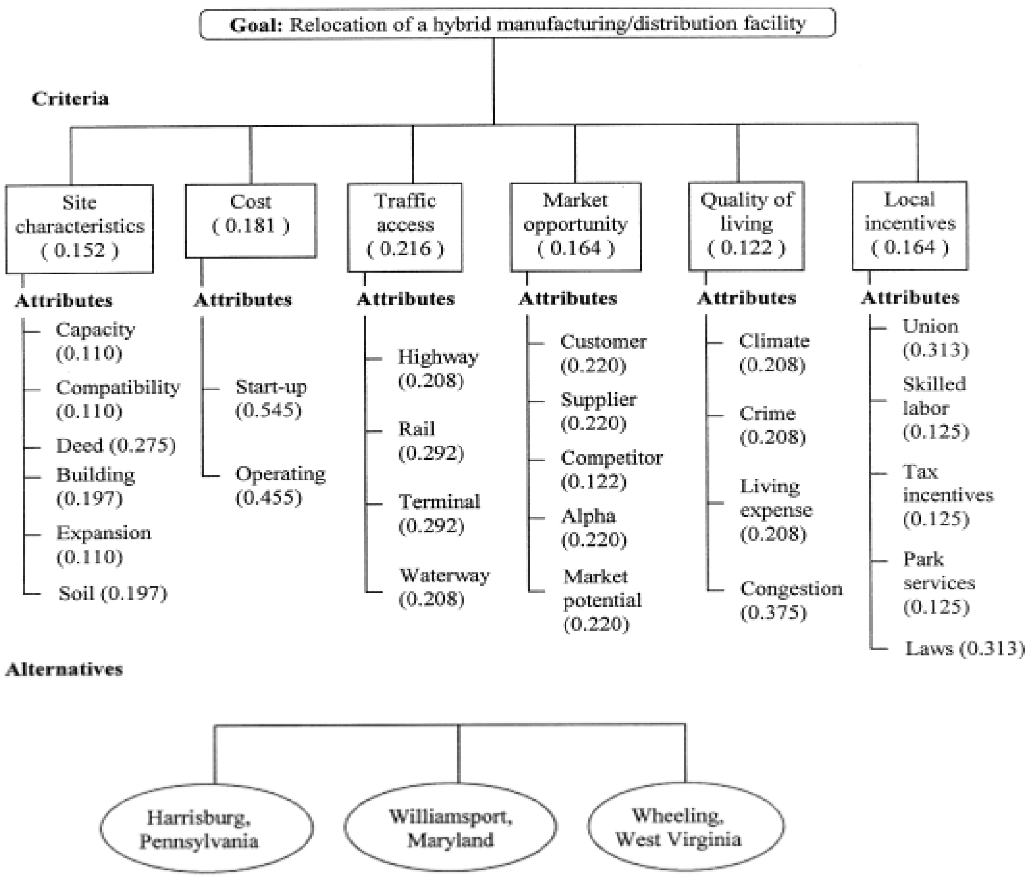

Figure 4:A hierarchical representation of the relocation of a hybrid manufacturing/distribution facility (Min et al., 1999, p. 80)

Advantages

of AHP Application to Locate Hybrid Manufacturing/distribution Facility

Relocates problems faced by a company that mainly produces and distributes home improvement hardware products (Min et al., 1999).

- AHP model that has been proposed helps to find the most favored site and its comparative advantage above other candidate sites.
- AHP model can handle multiple inconsistent objectives like reducing costs, maximizing market opportunities, local incentives, and traffic accessibility.
- Helps location planner to analyze the different transactions over the competing objectives as well as the inferences of strategic location decision.
- Unlike multiple objectives programming (MOP), AHP approach captures numerous realistic dimensions concerning several location factors and poses little computational challenges (Saaty, 2012).

Disadvantages

- The AHP model solutions remain insensitive to changes in the importance of market opportunity and site characteristics (Min et al., 1999).

1.1.5 Manufacturing Company's Application of Combined SWOT & AHP

AHP can be defined as a multi-criteria decision making approach that helps express the overall decision making operation through decomposing complex problems into a multilevel hierarchical structures of criteria, objective, and alternatives (Görener, Toker & Uluçay, 2012).

AHP may be used to conducts pairwise comparisons in order to derive relative significance of the variable in all levels of the hierarchy and evaluates the alternatives within the lowest hierarchical level to make a better decision among the alternatives. AHP remains an efficient decision making technique particularly when subjectivity occurs and it is mostly suited to address problems where decision criterion could be aligned in a hierarchy into sub-criteria.

Also, AHP can be utilized to identify relative priorities concerning absolute scales from both continual and discrete paired comparisons in multilevel hierarchical structures (Görener et al., 2012). According to Görener et al. (2012), the prioritization mean is achieved through assigning specific comparison scale to represent the comparative significance of the criteria. Pairwise comparison of these factors matrices offers the mechanism for calculating the importance.

The AHP approach is centered on three principles, including the model structure, comparative judgment of alternatives and criteria, and synthesis of priorities. AHP can be used to solve numerous decision making problems. The first step requires a decision problem to be structured as a hierarchy (Görener et al., 2012). Initially, AHP breaks down a complicated multi-criteria decision-making problem into hierarchies of interconnected decision elements (decision alternatives, criteria). Using AHP, decision criteria, alternatives, and objectives are organized in a hierarchical structure the same as a family tree. Moreover, a hierarchy has a minimum of three levels, consisting of overall goal defining the problem on top, multiple criteria defining alternatives in the middle, in addition to alternatives at the bottom (Saaty, 2012).

This study uses AHP to prioritize SWOT elements. After the problem is decomposed and hierarchy created, prioritization process commences to find out the relative significance of the criteria. In all levels, the criteria are compared pairwise in accordance with their level of impact and centered on the specific criteria in the higher levels. Multiple pairwise comparisons in AHP are based on a scale of nine levels standardized comparison (Görener et al., 2012).

SWOT-AHP Model Analysis

Görener et al. (2012) emphasize that AHP can perform comparison between analysis of factors to prioritize them through the eigenvalue calculation. The weightiness of these factors in similar SWOT analysis is not quantified to calculate the influence of every factor on the projected strategy alternatives. In the same way, SWOT analysis does not present a way of methodologically identifying the relative importance on the criterion or to evaluate decision alternatives in line with the criterion. To solve this inefficiency, the SWOT structure is modified into a hierarchical framework and after which the model is integrated with AHP using its eigenvalue calculation methodology. The objective of employing AHP within SWOT frame intends to systematically qualify factors of SWOT and equating their strengths (Görener et al., 2012).

Steps of SWOT-AHP Integration

The proposed methodology is applied in 3-steps.

Step 1 –The firsts step is listing the substantial internal (weaknesses and strengths) and external (threats and opportunities) factors for performing strategic planning, consisting of the SWOT analysis.

Step 2 – This step uses pairwise comparison in order to capture the weights of every SWOT group.

Step 3 – In this final step, AHP is utilized in deriving the relative priorities for all factors in the SWOT groups. Eventually, the overall factor weight rank may be got by multiplying the specified group weight by the factors local weight (Görener et al., 2012).

In this case study, SWOT analysis has been integrated with AHP in order to ensure factors are commensurable and to support a further quantitative basis during strategic planning. This improved approach has been widely employed and studies in various areas: by way of applications, an integrated SWOTAHP methodology has been utilized in determining the outsourcing decisions for marketing of sports, evaluating the tourism revival strategic promotion plan, evaluating the management strategy of forestland states, analyzing global competitiveness of machine tools manufacturers, strategic planning of national resources management, establishing the strategies for chemical industry in Turkey, determining the business strategy within textile corporation, formulating the strategy of safety transportation of bulky liquid chemicals using tankers, strategic implementation of Mozambican integrated water resource management, shipping registry assortment in maritime transportation sector, and investigating marine fatalities at the Strait of Istanbul (Görener et al., 2012).

Method and Application

The key ideal in employing the AHP within SWOT frame is to methodologically assess the SWOT factors and turn them commensurable with regard to their weightiness. The AHP framework may be derived from SWOT matrix, which is divided in three sections as follows (Görener et al., 2012):

- Goal to be attained by the decision.
- SWOT groups
- Factors incorporated within every SWOT group (also called sub-criteria).

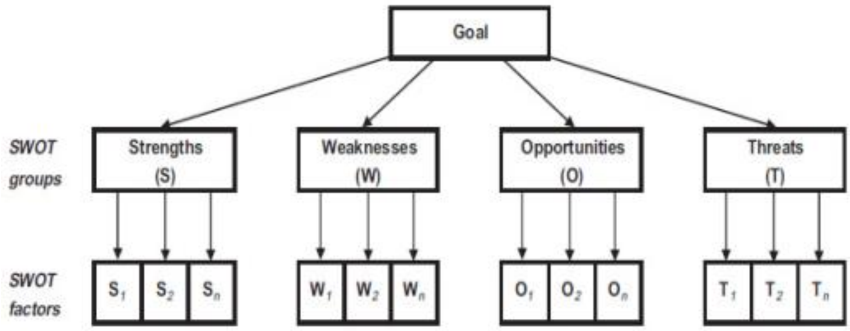

Figure 5:Hierarchical structure of the SWOT matrix.

Results

The case study indicates that SWOT analysis enhances the AHP carried out on a company which manufactures cooker hoods at Istanbul, Turkey. The firm frequently exports its goods to more than fifty counties across the globe. After the digitalization of SWOT framework with AHP, through the attained aggregated matrix, deriving the priorities or the vector weights for the factors and groups analyzed was possible (Görener et al., 2012).

Employing determined priorities of SWOT factors can be developed using a management technique or supported for crucial decisions. Consequently, these results may be utilized for constituting a set of suitable strategy alternatives for a company. Future research can enhance the usage of fuzzy logic frame using AHP methodology to more efficiently evaluate cases with ambiguity. Lastly, any multi-criteria decision-making methodology may apply rather than AHP for comparison (Görener et al., 2012).

1.1.6 A hierarchical model for the location of perinatal facility in the Rio de Janeiro municipality

Cover-type hierarchical model is usually connected to emergency medical service (EMS), which comprise of the advance life support (ALS) and basic life support (BLS) units. EMS facilities are often described in a sequentially inclusive hierarchical framework. They are known as two-tiered EMS systems (Galvao, Acosta & Boffey, 2002).

The importance of Hierarchical location models are growing in telecommunication networks design. The issue of locating concentrators within a computer communication network in which a concentrator may be linked to another concentrator can be addressed using hierarchical technique (Galvao et al., 2002).

3-level hierarchical models for locating perinatal facilities:

In perinatal and maternal healthcare, both babies and mothers can be classified in various risk categories consistent with specific clinical criteria (Galvao et al., 2002). For example, there is low and high risk category for mothers and low, medium as well as high risk categories for mothers. Four key levels of systems connected to perinatal and maternal care in Rio de Janeiro, Brazil and other regions include Basic Units (Level 1), Maternity Homes (Level 2), Neonatal Clinics (Level 3), and General Hospitals

(Level 4) (Galvao et al., 2002).

Results

Restrictions (2) make sure level 1 services for every mother-to-be. Restriction (3) indicates that births occur at either neonatal clinic or maternity home. Restriction (4) reflects the mother-to-be proportion in need of level 3 service so as to give birth. Restrictions (5) represents the referral constrains. And level (6-8) state that level 1, 2, & 3 services could only be received at locations where suitable level facilities are situated. Restriction (9) avoids location of various types of facilities within a similar site. Restrictions (10-12) are budget constraints, while restrictions (13-14) describe the nature of variables. Distances are the only cost in the objective junction (Galvao et al., 2002).

1.1.7 A customer oriented approach to a warehouse network evaluation and design

The Analytic Hierarchy Process (AHP) can be defined as a systematic procedure by which elements of all problems in the form of hierarchy are represented. AHP may be utilized to analyze the customer-specific needs for logistic service as well as to evaluate the alternative warehouse operator (Korpela & Lehmusvaara, 1999). The AHP-center analysis results in customer-specified priority for all alternatives warehouse operators. This priority defines how well particular warehouse operators are required to meet some customers' performance obligations. To analyze and design a warehouse network for an organization, AHP and MILP (Mixed Integer Linear Programming) can be integrated effective results (Ashraf et al., 1998). The basic principles for this approach include:

- Outsourcing warehouse activities such as only using third party warehouse operators.
- This method is preceded by an evaluation to describe the ideal possible locations for the warehouse, to identify the feasible alternatives warehouse operators, and collecting widespread information o them (Korpela et al., 1999).

Therefore, the aim of the proposed method is to help in determining the type of warehouse operators of the alternatives that are feasible would be incorporated to distribute the company's network. By including AHP approach in the process, every customer's preferences and requirements for logistic service could be analyzes and prioritized, and alternatives for warehouse operators could be analyzed in customers-focused way. Also, by employing AHP-Analysis results such as the priorities for every alternative operator from all customers viewpoint, as the source of MILP-optimization, the network of the warehouse may be designed based on any applicable customers service element rather than the costs only (Korpela et al., 1999).

In this regard, the AHP remains an appropriate tool for aiding this decision process through enabling the application of both objective information and subjective judgments.

The proposed method comprises the following steps

1. ***Preliminary Analysis*** – According to Korpela et al. (1999), this include highlighting the objectives for warehouse network design issue, identifying the ideal potential locations for setting up the warehouse, and describing the alternative warehouse operators and collecting and

analyzing information regarding each aspect of their operations. Data can be collected by directly visiting and holding interviewing the alternative warehouse operators.

2. ***Defining the Final Evaluation Issue*** – This stage concerns defining alternative operators of which the ultimate choices would be made. The warehouse operators who fail to satisfy the basic qualifications like cost level and customer service are removed from the final evaluation (Korpela et al., 1999).
3. ***The AHP-based analysis*** – In this phase, (1) representatives of every client affected by the final decision define the each criterion they employed for analyzing the alternative warehouse each warehouse operator, and determine the requirements about all criteria, (2), each criterion is prearranged into customer-specific AHP-hierarchy, and lastly (3) the representatives of all clients derive priorities for each criterion and the equivalent requirements (Korpela et al., 1999).
4. ***MILP-based optimization*** – This phase is rooted maximizing customer satisfaction whereas considering the relevant limitations. Rather than costs, priorities of customers are utilized as the optimization basis.
5. ***Implementation and follow-up*** – Once the selected warehouse in practice is has been implemented, the AHP-models may be used in supporting periodical reviews of the warehouse network actual performance. The MILP-centered optimization model may be then employed in reviewing the general warehouse network (Korpela et al., 1999).

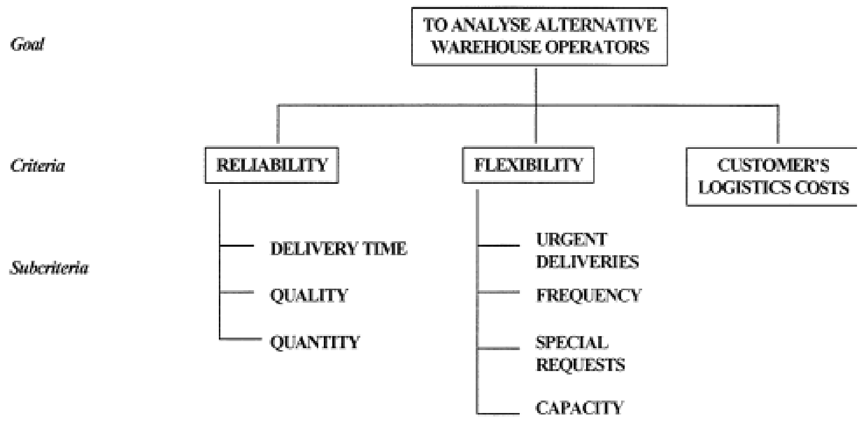

Figure 6:The AHP hierarchy for analyzing the alternative warehouses (Korpela et al., 1999)

Advantages of AHP-based Analysis

- Decomposing a complex and multi-criteria problem into a hierarchy in which each level have a small number of manageable elements that are later decomposed to another group of elements (Saaty, 2012).
- Establish priorities from the elements in all levels of the hierarchy.
- Synthesis the priorities of elements in order to determine the overall priorities for the company's decision alternatives.
- Does not require company managers or decision makers to make arithmetic guesses.
- Flexible

Disadvantages

- AHP classical method violates the appropriate application of scale of measurement with incorrect and implicit assumption that outstanding remains five times greater than unsatisfactory.
- Since the customers do not essentially possess previous experience on utilizing the warehouse being analyzed, the analysis is anticipated levels of performance of each alternative warehouse operator are a joint work between the corporation and customer's representatives (Korpela et al., 1999).

1.1.8 Analysis of the Turkish Consumer Electronics Firm using SWOT-AHP method

The Analytic Hierarchy Process (AHP) refers to a theory of measurement via pairwise comparisons and depends on the experts judgments in order to derive priority scales. These scales measures intangibles in comparative/relative terms. Judgments could be inconsistent, hence AHP is applied to measure this inconsistency and improve judgment to obtain better consistency (Şeker & Özgürler, 2012).

The AHP systematic approach to commensurability and decision problems is essential properties in SWOT analysis. Additional significance from SWOT analysis may be accomplished through conducting pairwise comparisons between SWOT factors and then evaluating them with eigenvalue technique as employed in AHP (Ashraf et al., 1998).

This study integrates AHP with SWOT analysis to provide quantitative measures of importance for all factors on decision making (Şeker et al., 2012). This can be achieved in four steps.

Steps of Performing SWOT-AHP Integration

Step I: SWOT analysis is performed - SWOT analysis is utilized to analyze the condition of Turkish company from consumer electronics industry by judging it on strengths and weaknesses and opportunities and threats as demonstrated below.

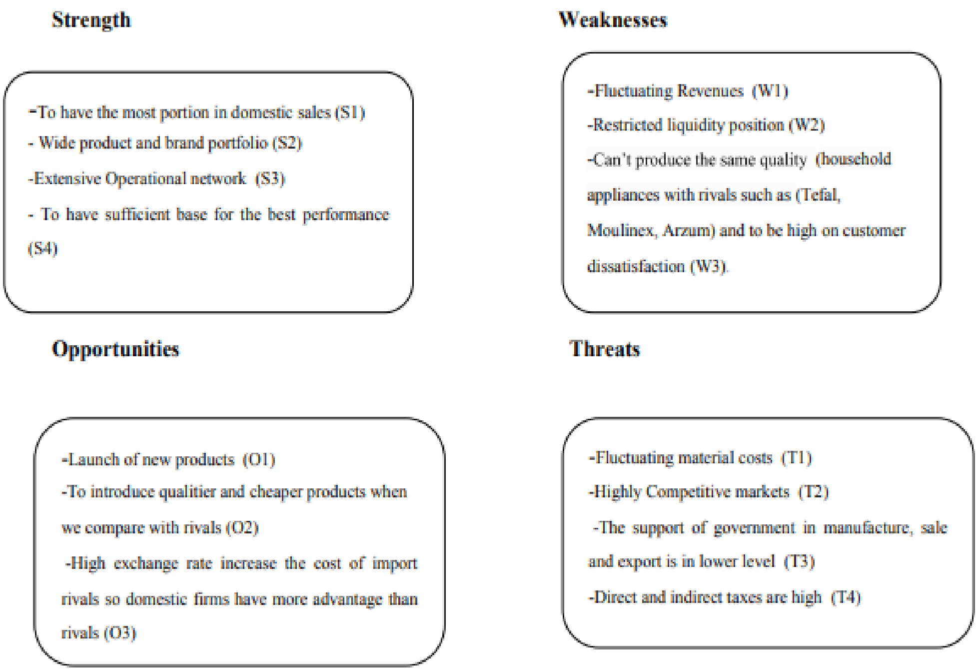

Figure 7:SWOT factors of the company (Şeker et al., 2012).

Step II – AHP method in this phase is combined with SWOT analysis. The upper level depicts the strategies are evaluation of strengths, weaknesses, opportunity, and threats as demonstrated below.

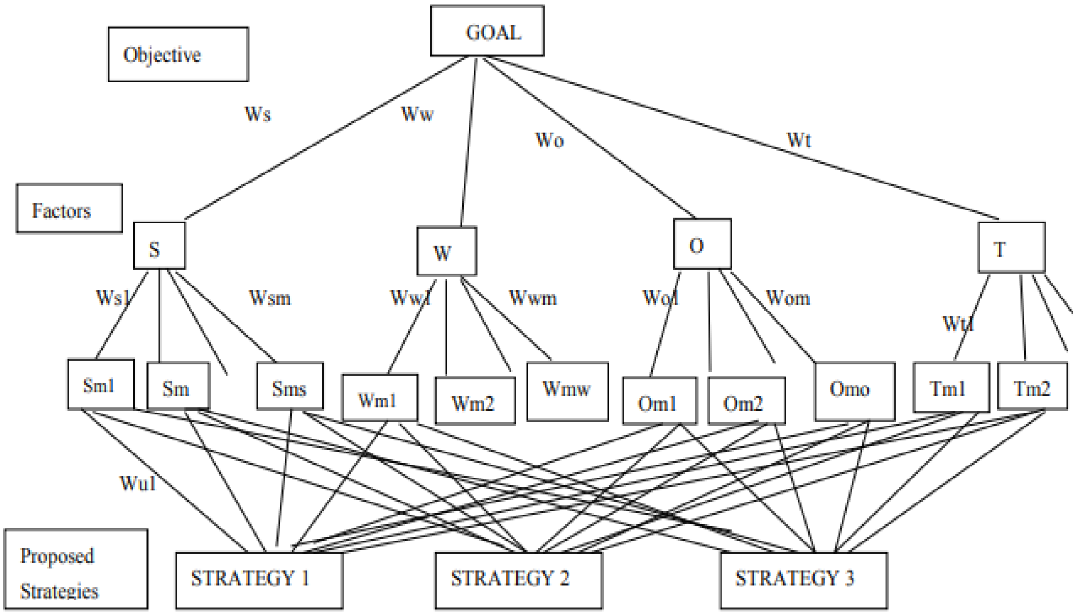

Figure 8:Hierarchic structure in making decision for the priorities of strategies (Şeker et al., 2012).

Step III: Pair-wise comparisons performed with regard to 3 objectives and 4 SWOT groups.

Step IV: The results are applied in the evaluation process.

Results

The method used was valuable in evaluating the critical factors in firm's strategic planning apply them to develop effective strategy (Şeker et al., 2012). Pair-wise comparisons were made by expert's judgments to get priority scales for strategies and SWOT factors of the electronics firm. The results indicate that the company need to focus on alternative suppliers to reduce cost of raw materials as cost remains a problem in Turkey and throughout the world (Şeker et al., 2012).

Advantages

- Combination of AHP with SWOT analysis provide more comprehensive tool for decision making for effective strategic plan that utilizing a conventional method.
- Priorities can be assessed using AHP quantitative method.
- AHP method measures inconsistency and improve judgment to obtain better consistency
- Disadvantage
- AHP users have to depend profoundly on their intuitive judgment and experience

1.2 Scope

The scope from this project is to find new method to classify the equipment criticality. Nowadays in most of the industrial plant they use the traditional method which uses the risk matrix. Using AHP will help to prioritize the equipment that comes under the same risk for maintenance, inspection and other related activities.

1.3 Methodology

Using AHP in the equipment criticality will require a lot of discussion to identify the criteria of ranking and the ranking it self. The criteria of the criticality have been identified based on two factors:

- Experience from the company senior engineers. (With the Involvement of all parties)
- The common industry practices.

To find the right ranking for each criteria against the equipment, survey have been circulated for individual in different departments and the average was taken in the analysis.

The equipment that will be in the analysis was chosen from the company database. The equipment carries different criticality and total 12 equipment are selected. The company criticality method is using the Risk matrix that will be explained in the following chapter. Basically, it is a mathematical module to give a rating for the consequence on safety and Business. Then give the criticality on alphabet, where A is the most critical equipment.

The equipment selected in the analysis are below:

- 3 equipment criticality A
- 5 equipment criticality B
- 3 equipment criticality C
- 1 equipment criticality D

1.4 Objective

The objective from this paper is to come up with new criticality classification method that will help in prioritize the equipment importance. The old method based on alphabet classification as mentioned before. This kind of classification can cause some issues in case of having two equipment carrying the same criticality needs maintenance or inspection at the same time. AHP will help to resolve this issue in which each equipment will have its own weight.

CHAPTER2: CURRENT EQUIPMENT CRITICALITY CLASSIFICATION

Companies face multiple equipment in terms of variations and number in equipment monitoring. Therefore, critical equipment monitoring classification is important to make sure objectivity in equipment monitoring to facilitate maintenance process. Moreover, equipment monitoring requires clear and rational classification. To receive the best manufacturing equipment, it is crucial to prioritize where actions are performed. Classification of equipment criticality allows for correct prioritization of the equipment from influential factors, such as quality, safety and environment, cost of improvement action, delivery performance, and demand of productions flow. Applying AHP in critical machine classification helps in judging the best alternative actions and decisions for handling the critical equipment (Abdi, 2013).

Knowing which machines are critical is essential to be capable of prioritizing breakdown repairs succession, operated-based maintenance improvement and implementation, preventive maintenance intervals and activities, condition-based maintenance intervals and activities, and improvement work programs (Bengtsson, 2016). Classifying equipment criticality helps the corporation in attaining a better priority. Nevertheless, additional functions within a company can benefit from an equipment classification. For instance, production engineering and production management may both be valuable in the classification process and gaining from the outcomes of the classifications in their everyday work. This similarly helps to achieve an accord between them and the department of maintenance.

The equipment classification may be utilized as accomplish a consensus about the location in the factory layout the greatest critical machine is positioned. This needs to be a main tool for how everyday activities must be prioritized. However, the industrial unit has an overall priority order preceding the classification, including environment and safety. If the maintenance department obtain a work order regarding immediate safety risks like washer fluid or oil leak, it is prioritized. Apart from prioritizing various initiatives in the factory, machine classification must to be also perceived as a long-term model in prioritizing where improvement measures would result in less critical obstructions in the future (Bengtsson, 2016).

Production Management: This may utilize a number of perspectives to minimize the criticality of manufacturing cell, such as scaling of buffer dimensions at critical equipment, prioritizing improvement work, performance of operator-based maintenance, and increasing training and education at critical equipment.

Production Engineering: The department of production engineering may utilize a number of perspectives to decrease the criticality of manufacturing cell, including prioritizing replacement investments, develop redundancies at critical sections, and develop error proof systems at critical machines (Bengtsson, 2016).

Maintenance Department : To decrease the criticality of manufacturing cell and as a tool in prioritizing immediate actions, the maintenance can employ a number of perspectives, such as disturbance repair sequence (classified as deferred sequence), breakdown repair sequence (classified as immediate sequence), Spare parts storage dimensioning, Prioritize improvement work, Developing and implementing operator-based maintenance, increasing competence level on critical equipment through mentoring and education program, and developing and implementing predetermined and condition maintenance, intervals and activities (Abdi, 2013).

Development and Implementation of Condition Maintenance

Using equipment classification as means to implement condition-based maintenance is possible. At large manufacturing sites, monitoring every machine is uneconomically feasible. By applying AHP equipment classification model, it is probable to sort out a variety of machines in different aspects to utilize in implementation of condition-based maintenance (Bengtsson, 2016).

To classifying the criticality of machines, the goals are placed at the top level of analytic hierarchy process, whereas the criteria are positioned on the second level. According to Abdi (2013), these criteria are employed to judge the alternatives on the bottom level. These helps in evaluating a set number of alternatives. Each element in a specified cluster of hierarchy is then compared in pairwise sub-goals that require qualitative and quantitative fashion with reference to importance or contribution for the basis of cluster. This classification method helps in selecting most feasible maintenance strategy for critical machines. One example of application of AHP is load shedding operations of large pulp mills. They are used to rank load in accordance with their significance for load shedding purpose.

2.1 Overview of Current Industrial Practice

Some frameworks and methodologies for equipment criticality classification have been developed and applied industries. One of the most common methods is using AHP to perform criticality evaluation (Bengtsson, 2016). The model is commonly employed to derive comparable metrics of criticality as well as to classify the machines into three categories, including essential, vital, and desirable. The most proposed scheme is a classification of spare parts using an assortment of multiple attributes. In merit of numerous possible operational attributes to be takes into account, industries created a decision diagram that integrates with AHP. An inventory policy matrix has been described to link the various classes of equipment with the potential inventory management guidelines and policies in order to identify the most significant strategy for the machine or spare stocks (Abdi, 2013).

Classification of equipment can also be based on control criticality and process criticality. Defining criticality or priority among equipment concerns concurrent consideration of multiple criteria, such as intangible and tangible factors. However, classifying these factors may be a complex task and a great challenge. During classification of critical machines, uncertainty and ambiguity factors taken into consideration when inventory items criticality are being defined.

Multi-criteria decision model

The AHP is a decision tool which can deal with structured and semi-structured decisions with multi-criteria and multi-person inputs. Equally, it is a decision-rule model that can relax the measurement of correlated aspects to subjective management input on multiple criteria. AHP accepts inconsistencies in decision-making perceptions or judgments. AHP also allow users to directly input judgment data with no necessity of mathematical proficiency. Users of AHP can similarly structure complex problems in a hierarchy. Additionally, AHP can be understood easily and may effectively solve both quantitative and qualitative data. AHP also avoid cumbersome mathematics, but involves decomposition principles, priority vector generations and synthesis, and pairwise comparisons (Abdi, 2013).

The superiority of AHP has been evidenced by empirical utilization in different research in areas like mining, healthcare, manufacturing, missile systems, project management, planning, and new product development (Bengtsson, 2016). Consequently, AHP has been applied to make decisions that concern evaluation, ranking, and selection of machines and Information Technology systems. In order to develop hierarchy of attributes and objectives that enable a prioritization scale to be established, an extensive review of the proportionate literature need to be conducted. This review focuses on equipment criticality aspects in addition to their relationships between logistics and maintenance perception. Thus, two categories of attributes are distinguished, such as maintenance factors and logistic factors.

2.1.1 risk matrix

Risk matrix are used in determining the magnitude of risk and whether the whether the risk is sufficiently or insufficiently controlled. It is essential to note that matrix makes a bad decision making tool, but is most suitable to rank events (Day & Kanopy, 2014). There is inadequate granularity in risks matrix to employ it for anything except emphasize that particular events are not good, while others remain less so. Decisions must be centered on principal analysis that would tell what causes undesirable event and what action is taken by a company to control it. This kind of information would help make an informed decision. Risk matrix is composed of two ordinal rating scales, together with quantitative descriptions alongside its axis. As a result, it is difficult to assign real numbers to matrixes and thereby calculations using it. Nevertheless, it may provide quantitative scores that show where category of an even lies (Bengtsson, 2016).

A risk matrix has two dimensions such as severe and probable unwanted event. The two dimensions form a matrix. Combining probability and severity gives any event a position on a risk matrix, many risk matrixes have a minimum of three areas as shown below:

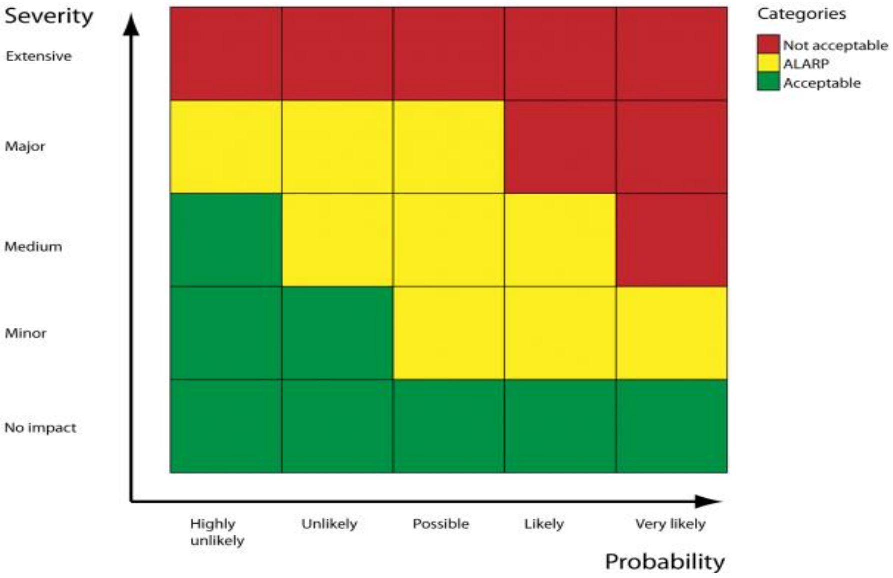

Figure 9: Risk matrix sample

1. **Extreme/high severity/high probability** (normally at red cell) - Indicate that an event requires more or a lot of control measures to reduce severity or probability. There are several events that do not reach this category. These risks are most critical and need to be handled on the basis of high priority. The project team must take immediate action in order to eradicate the risk entirely (Day et al., 2014).
2. **Medium** (normally in yellow cells) – Events falling in this area are judged as an area that ought to be monitored, although is controlled as low as logically feasible. Apart from thinking concerning eliminating the risks, changeover

strategies could also work effectively. If these situations cannot be addressed immediately, strict timeline should be set up to make sure that the issues are solved before they result in disruptions in the progress.

3. **The low Risk Probability/Low severity** (Normally in green cells) – shows that the risks of the event insignificant or not high enough, or is sufficiently controlled. Actions are not often to mitigate low risks category (Bengtsson, 2016).

Types of Risks used by Industrial Companies

According to Day et al. (2014), a risk assessment matrix refers to a project management model that allow quick view of possible risk evaluated on the probability or likelihood of risks and severity of consequences. As nearly all information required may be easily retrieved from risks assessment forms, risk assessments is easier to make. It is made using a simple table in which risks are categorized rooted in their probability and the type of consequence or extent of damages that the risk could lead to.

Application of the Risk Assessment Matrix

After the risk has been inserted in the matrix, within cells that corresponds to the right probability and consequences, the kind of risks that need to be addressed at what priority are visibly clear. All the risks put in the table falls in one of the categories, wherein colors have been utilized.

Risk management matrix is subsequent step in risk management process, and it is done after the first step of competing risks assessment form in order to identify the probable risks. Preparing risk assessment form is more complex task and concerns risks determination, determining the likelihood and the levels of impacts, collecting risk data, understanding consequence, creating risk prevention plans, and assigning priorities. Conversely, risk assessment matrix offers the project management team with quick review of risks and the priorities by which threes risks should be addressed (Day et al., 2014).

Application of Risk Management Matrix

To obtain a holistic analysis of the project various risks perspective a rising from the environment, a two dimensional management matrix should be used. The weighted likelihood of external project risks and immediate project risk create the matrix's two dimensions. The dimension of external project risk is based on multiple considerable factors as is applicable in a particular context (Day et al., 2014). Some of the five factors that may be employed include technological risks, domestic climate risks, economic climate risks, social risks, and political risks where the project is being implemented. Immediate project risks dimension is a combination of factors like risks that relates to complex and large projects, failure by contractors, mode of contract, conceptual difficulty, and involvement of external agencies in project management (Bengtsson, 2016).

How the Risk Matrix may Guide Selection of Risk Management Strategies

Reduction of Risk – The organization attempts to reduce either the consequence or probability of the risk (Day et al., 2014). Similar examples comprise safety of equipment and employee safety training, both which are proper interventions to solve events such as employee injury caused by a machine. Employer can also reduce any severe negative consequences of risk to business through a succession plan.

Avoid Risk – The organization should take in order to avoid risk. This means the organization undertakes an activity. An example is a farmer's decision to not to plant lavender as the planting conditions are not suitable and the possibility of cross failure remains high.

Transfer Risks – According to Day et al. (2014), the company can transfer risks to an insurance company, which would pay compensation when the event takes place. These may include liability insurance, life insurance, and disability insurance. Moreover, due to frequent occurrence of accidents, it would be better off if the business owner acquire disability insurance and car insurance. The organization may also progress well if the life insurance of the owner offers enough cash to enable the partners or spouses to learn how to satisfy the owner's responsibilities (Day et al., 2014).

Retain Risk – The Company understands that unexpected events might occur and would opt to retain such risks that are less consequential to the business. The company face numerous risk like bounced checks or employee quitting (Bengtsson, 2016). Company owners need to invest money and time to safeguard the business in case these events take place. Business owner may invest capital to create a will or succession plan. Another potential risk retention strategy that a business should adopt is saving money when it is performing well so as to counterbalance the losses incurred from the bouncing checks and others.

A risk matrix is a tool utilized during risk assessment and risk management to define the risk level and by taking into consideration the category of likelihood or probability against the class of consequence severity. Risk matrix is a way of increasing visibility of risks and facilitates management decision making (Day et al., 2014).

2.2 Importance of Prioritizing

Delayed maintenance and inspection programs caused by budged fluctuations and other factors may contribute to deteriorated equipment conditions and expose device users to a higher level risks. Consequently, there is necessity for methods to assist select the most critical equipment and cost-effective maintenance projects to minimize and control risks for their users under the existing budget laminations (Brookhaven National Laboratory, United States, Vesely & Rezos, 2015). By doing so, an organization may select and implement the most critical and cost-effective projects or equipment within the budget constraint and adjust its maintenance program to incorporate budget fluctuations. AHP is the usually employed methodologies to analyze and quantify judgment. In this case, AHP should be utilized to quantify the risks of performing a specific maintenance and inspection program centered on the judgments of expertise and experienced engineers. An AHP can be developed to validate how the method could help industries to prioritize maintenance projects and inspection programs centered on the results derived from a budget or workshop constraints (Bengtsson, 2016).

Real priorities are centered on the importance of maintenance and inspection work to be performed as well as its benefits for production area or the entire company. The work priority takes into considerations the consequences of failure to conduct maintenance work and the condition of the equipment or project as measured in the course of inspection (Bengtsson, 2016). In a well-structured organization, about 90% of every maintenance work results from condition monitoring, such as basic inspection and interviews with plant operators. With real priorities, extra work could be planned, and then it could be schedules and carried out in an effective manner.

To keep up with the current technological improvements as well as the increasing anticipations of industrial units, inspections, testing, and preventive maintenance need to be reviewed continually (Bengtsson, 2016). Due to discontent of just following the recommendations of manufacturers, clinical engineering departments and other field all over the globe have started to use more cost-effective and efficient maintenance strategy. In particular, many companies have adopted AHP approach, which provides a large statistical breakdown data set to determine optimum intervals and ranking for routine inspection and maintenance scheduling. Equipment that is largely pneumatic, fluidic, or mechanical usually needs to prioritize for extensive maintenance. A system is classified to have average maintenance when it necessitates only safety testing and performance verification. Equipment that get merely visual inspection, safety testing, and a basic maintenance check is considered as having least priority for maintenance (Brookhaven National Laboratory et al., 2015).

Prioritization is also significant in determining operational impact or mission criticality of a machine. Operational impact describes the degree to which equipment is valuable to the service provision such as care delivery process of hospitals. For instance, Magnetic Resonance Imaging device could be very important consistent with a hospital mission but less critical in operational risk by use. Mission criticality relies on availability and utilization of typical or alternative equipments (Bengtsson, 2016).

In planning and design phases, critical equipment and projects are developed in order to accommodate all the essential safety criteria to make sure safe and comfortable use under all probable conditions (Brookhaven National Laboratory et al., 2015). Whereas these critical facilities start to deteriorate under normal usage, an appropriate maintenance and inspection strategy has been confirmed to be the most useful tool to guarantee that the facilities progress to function as originally expected and offer the desirable level of service. Additionally, a good maintenance prioritization and strategy would minimize the deterioration and expand the service life of the equipment or facility, enabling resources that could have or else been exhausted to rehabilitate or reconstruct the equipment/facility to be utilized for other purposes (Bengtsson, 2016).

Identifying and utilizing new priority guiding principle would yield quicker results with minimal breaks in work and enhance the scheduling, planning, and controlling to inspection and maintenance. Nevertheless, this simple process of enforcing guidelines may take time. Sometimes priority is emotional and is based on feelings rather than objective judgment of importance (Brookhaven National Laboratory et al., 2015). Moreover, the importance of the maintenance task is judge is judge as it associates with the production domain in which the requester operates. For instance, an individual in operations might desire to get a maintenance job executed simply to do away with it on his/her mentality. It is usual to observe that several these forms of priorities are requested via a standing work order number or verbally, sidestepping the utilization of manual or computerized maintenance work request practice.

Since maintenance serve as service to many operators, these methodologies of requesting maintenance task would endure to rise if strict rules and written requests for standing work orders failed to be adopted. This occurs because it is very convenient for the requesters to get somebody else document the job request than to do it alone. Another explanation why priorities are sought after is because they normally offer the means to have a maintenance task completed with a considerable timeframe. Requestors of job are aware when everyone within the organization abuses the priority framework. They similarly know that in case they act nicely and install a lower priority than is necessitated, their specific work would never be executed. Finally, this implies that the job request would be pushed through a greater priority than necessitated

(Brookhaven National Laboratory et al., 2015).

Generally, devices having low criticality score may be excluded from the inspection and maintenance management program of an organization and just get repaired when they breakdown. This category of devices are likely to have a low score value in proportion to criteria the criteria having higher weights like risk, function, and hazards and recalls alerts. Thus, the equipment management resources should not be used on this category (Bengtsson, 2016).

2.3 Issues in Equipment Classification

Simple uptime and reduction plans are often unsatisfactory in the performance communication. The use of statistically based self-reliance interval in forecasting to determine machine failure modes has become an increasing trend to demonstrate organizational dedication to regulatory agencies, investors, and the community, particularly as it concerns factors that directly impacts the industry and environment.

Failure to observe operating conditions – if equipment is being used, there are usually parameters and conditions that are transforming. When a condition changes out of specification, the plant of equipment operator must be able to determine the new state and act for that reason. If the machine does not warn its operator that a specific parameter has altered, it must be classified as a failure in observing operating conditions.

Human Error – This may be divided into 3 sub-groups, including human error maintenance mechanic, human error of craftsman, and human error of operator. The operator should never be when there is a failure. In its place, the error should be divided into various categories for assessment. An appropriate too for finding concrete main cause is employed is considered the human error root cause analysis.

Design Weakness – Tow different forms of design weaknesses exist. The first form is caused by inherent strength that leads to a component that cannot satisfy its role. The second form is somewhat associated with unsuitable design that results in failure elsewhere such as the component satisfactory but it contributes to failure in a different function (Brookhaven National Laboratory et al., 2015).

External Influence – also hold all sources of classification problems that affect the facility from outside. Thus, the solution cannot be found in the facility or equipment. Rather, external factors should be evaluation. Some of the external influences encompass environmental conditions in the factory, components and objects affecting the equipment, weather conditions, and failure of central IT systems (Bengtsson, 2016).

Other problems of classification are frequently criticized due to a series of drawbacks linked with AHP method (Day et al., 2014). They may be reviewed as describes below:

- In conventional development of the AHP, humans' judgments are represented as accurate or crisp numbers. Nevertheless, in multiple practical situations, the human preference tool is tentative and decision makers could be reluctant or incapable of assigning accurate numerical figures to a comparison judgment.
- Whereas the utilization of the discrete scale between 1 and 9 is advantageous than simplification, the AHP does not consider the uncertainty related to the mapping of an individual's judgment to a number.

- Its incapability to solve the intrinsic uncertainty and impression related to the mapping of the perception of decision makers to exact numbers.

CHAPTER 3: USING ANALYTICAL HERIACHY METHOD

As mentioned in the previous chapters, the equipment prioritizing is a very essential part in any industrial company. In this chapter, the prioritizing using analytical hierarchy method will be used.

3.1 Choosing of equipment

The equipment has been chosen from different criticality ranking from an industrial company based in Doha, Qatar. The company have a ranking process from A,B,C & D criticality equipment, where A is the highest criticality and D is run to fail criticality. The description of the chosen equipment are shown below:

1. Pressure relief valve (E1):

The pressure relief valve is an equipment that allows the pressurized fluid to flow out of the system. It designed to open at a set pressure to protect vessels, exchangers, pipeline and other equipment from being subjected to pressures that exceed their design pressure. The criticality of this equipment in the company is A, since it’s a safety equipment.

2. Pressure vacuum relief valve (E2):

The vacuum relief valves are protection equipment that normally are fixed on top of storage tanks to protect it from being ruptured or collapsing. By pumping the fluid from the tank and the liquid level go lower, the vapor pressure will decrease which needs to control the atmospheric pressure. In such case, the VRV will open allowing some air to go inside the tank. The criticality of the VRV in the company is A.

3. Air supply pot (E3):

This equipment is to supply air for one of the valves in the plant. Failing to supply air will cause the valve to fail and the consequences on the valve failure is Partial loss of firefighting capability leads to escalation of fire and serious injury to user. The criticality of this equipment is A.

4. Sulfinol absorber, carbon steel column (E4):

The sulfinol absorber is an essential stage in the gas processing. The function of this equipment is to remove H_2S, CO_2, COS and mercaptans from gases in order to transfer it to natural gas. The criticality of this equipment in the company is B as any failure will be business risk.

5. Molecular Sieve Beds (E5):

The molecular sieves is a material that used in the oil & gas industry to remove the moisture from the fluid. The molecular sieves will be inside a huge vessel and any carryover from the moisture can cause serious issues to the process. The criticality of this equipment is B because there is a spare vessel in case on is failed.

6. Mixed refrigerant compressor after cooler (E6):

This equipment is important to cool the mixed refrigerant using cooling water. The mixed refrigerant consists of methane, ethane and propane. Any failure of this equipment will cause shutdown and loss of production. The criticality of this equipment is B.

7. Reaction furnace (E7):

The furnace is an equipment that used to increase the flow temperature. The heat provides energy for process reaction. This equipment is very critical in the plant because of the energy provided and the high temperature. The criticality ranking of this equipment is B.

8. Slug catcher (E8):

The slug catcher is the first onshore facility in the plant. Basically it's the pipelines that receives the gas from the wellhead and separate it to water, gas and condensate. The criticality of this equipment comes from the operation parameter in which the operation pressure and temperature are 149 bar, 90o C respectively. The criticality for this equipment is B.

9. Heat exchanger (E9):

The heat exchangers are equipment to heat or to cooldown the flow by using heat transfer. In which, one side of the exchanger will be hot fluid and on the other cold one. In this case the exchanger being used to cool the flow gas from the compressor using cooling water. The criticality of this equipment is C.

10. Liquid incinerator (E10):

This kind of equipment operates at a temperature more than 1000oC. by definition, Incineration is a waste treatment process. This equipment is used to treat the process water. The criticality for this equipment is C.

11. Chemical and Solvent Storage tank (E11):

The storage tanks are containers to handle liquids or compressed gas. All of the tanks are combined with pumps, valves, transmitters and vacuum relief valves. The critical of this equipment is C.

12. Fuel gas filter (E12):

the fuel gas filter is basically an equipment that used to remove whatever is slipped in the gas such as debris and small particles that could cause damages to the down stream equipment. The criticality of this equipment is D.

3.2 Criteria selection

The criteria of selection is one of the most important step in the AHP analysis. From the literature review and the introduction, it is certain that the criticality of the equipment depends mainly on the consequence of failure. The consequence of failure can affect two risks.

1. Safety, Health and Environment risk (SHE)
2. Business risk.

The common practice in the industry that the SHE risk is more important than the business risk. Safety, health and environment is more valuable than money. The SHE and Business risk is the first level of the analysis. The SHE risk can be divided into three sub criteria which are:

1- fire and explosion.

2- Effect on the environment.

3- Effect on personal.

When trying to analyze the business risk, the main consequence of failure can affect the business is loss of production. The cost of the equipment or the repair is marginal comparing to the stop of operation. So, loss of production will be the only sub criteria for the business risk.

Questioner will be distributed in the company to find the weights of the criteria. The participant in this analysis will be selective in which, there will be participant from different department such as operation, engineering and maintenance department. The location of the equipment and the consequence of failure is a well-known for the participant, in which they are senior staff and expert. At the end the average will be taken, and the analysis will start. Copy from the questioner is shown in the Appendix.

3.3 Applying the AHP method

The average has been taken from the questioner to find the final weight for the criteria. The final weights is shown in the tables below:

Table 1:

First level of AHP

First level criteria	SHE	Business
SHE	1.00	2.00
Business	0.50	1.00

Table 2:

Criteria weight average

#	Equipment	criticality	Fire/explosion	Effect on the environment	Effect on personal	Production loss
1	E1	A	7.67	6.22	7.44	4.78
2	E2	A	7.33	6.44	7.00	3.89
3	E3	A	6.56	1.33	4.78	3.67
4	E4	B	5.33	3.00	5.00	6.89
5	E5	B	5.00	3.11	5.33	6.67
6	E6	B	4.89	2.22	5.11	6.78
7	E7	B	6.56	3.44	5.56	3.11
8	E8	B	9.00	9.00	9.00	9.00
9	E9	C	4.89	2.89	3.11	3.00
10	E10	C	5.11	4.89	2.78	3.22
11	E11	C	2.11	3.11	2.56	2.56
12	E12	D	1.00	1.00	1.00	1.00

Table 3:

criteria by criteria comparison

SHE Criteria	fire/explosion	Effect on Environment	Effect on Personal
Fire/explosion	1.00	2.33	0.78
Effect on Environment	0.43	1.00	0.33
Effect on Personal	1.29	3.00	1.00

The first step was to normalize the first level of SHE & Business risk and get the weight. Then the SHE criteria weights calculation was found. For the business criteria it is only one criteria so, the weight will be multiplied by the business risk weight. The tables below show the weights.

Table 4:

SHE & Business risk weights

First level criteria	SHE	Business	Total weight
SHE	0.67	0.67	0.67
Business	0.33	0.33	0.33

Table 5:

SHE criteria weights

SHE Criteria	fire/explosion	Effect on Environment	effect on Personal	Total weight
fire/explosion	0.37	0.37	0.37	0.37
Effect on Environment	0.16	0.16	0.16	0.16
effect on Personal	0.47	0.47	0.47	0.47

The second step was to find the weight for equipment for each criteria. Four tables were developed in order to find the weights.

Table 6:

Equipment weights with respect to fire & explosion

Fire/ explosion	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1	1.00	1.05	1.17	1.44	1.53	1.57	1.17	0.85	1.57	1.50	3.64	7.67
E2	0.96	1.00	1.12	1.38	1.47	1.50	1.12	0.81	1.50	1.43	3.47	7.33
E3	0.86	0.89	1.00	1.23	1.31	1.34	1.00	0.73	1.34	1.28	3.11	6.56
E4	0.70	0.73	0.81	1.00	1.07	1.09	0.81	0.59	1.09	1.04	2.53	5.33
E5	0.65	0.68	0.76	0.94	1.00	1.02	0.76	0.56	1.02	0.98	2.37	5.00
E6	0.64	0.67	0.75	0.92	0.98	1.00	0.75	0.54	1.00	0.96	2.32	4.89
E7	0.86	0.89	1.00	1.23	1.31	1.34	1.00	0.73	1.34	1.28	3.11	6.56
E8	1.18	1.23	1.37	1.69	1.80	1.84	1.37	1.00	1.84	1.76	4.27	9.00
E9	0.64	0.67	0.75	0.92	0.98	1.00	0.75	0.54	1.00	0.96	2.32	4.89
E10	0.67	0.70	0.78	0.96	1.02	1.04	0.78	0.57	1.04	1.00	2.42	5.11
E11	0.28	0.29	0.32	0.40	0.42	0.43	0.32	0.23	0.43	0.41	1.00	2.11
E12	0.13	0.14	0.15	0.19	0.20	0.20	0.15	0.11	0.20	0.20	0.47	1.00

Table 7:

Equipment weights with respect to Effect on Environment

Effect on Environment	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1	1.00	0.97	4.67	2.07	2.00	2.80	1.81	0.69	2.15	1.27	2.00	6.22
E2	1.04	1.00	4.83	2.15	2.07	2.90	1.87	0.72	2.23	1.32	2.07	6.44
E3	0.21	0.21	1.00	0.44	0.43	0.60	0.39	0.15	0.46	0.27	0.43	1.33
E4	0.48	0.47	2.25	1.00	0.96	1.35	0.87	0.33	1.04	0.61	0.96	3.00
E5	0.50	0.48	2.33	1.04	1.00	1.40	0.90	0.35	1.08	0.64	1.00	3.11
E6	0.36	0.34	1.67	0.74	0.71	1.00	0.65	0.25	0.77	0.45	0.71	2.22
E7	0.36	0.34	1.67	0.74	0.71	1.00	0.65	0.25	0.77	0.45	0.71	2.22
E8	1.45	1.40	6.75	3.00	2.89	4.05	2.61	1.00	3.12	1.84	2.89	9.00
E9	0.46	0.45	2.17	0.96	0.93	1.30	0.84	0.32	1.00	0.59	0.93	2.89
E10	0.79	0.76	3.67	1.63	1.57	2.20	1.42	0.54	1.69	1.00	1.57	4.89
E11	0.50	0.48	2.33	1.04	1.00	1.40	0.90	0.35	1.08	0.64	1.00	3.11
E12	0.16	0.16	0.75	0.33	0.32	0.45	0.29	0.11	0.35	0.20	0.32	1.00

Table 8:

Equipment weights with respect to Effect on Personal

Effect on Personal	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1	1.00	1.06	1.56	1.49	1.40	1.46	1.34	0.83	2.39	2.68	2.91	7.44
E2	0.94	1.00	1.47	1.40	1.31	1.37	1.26	0.78	2.25	2.52	2.74	7.00
E3	0.64	0.68	1.00	0.96	0.90	0.93	0.86	0.53	1.54	1.72	1.87	4.78
E4	0.67	0.71	1.05	1.00	0.94	0.98	0.90	0.56	1.61	1.80	1.96	5.00
E5	0.72	0.76	1.12	1.07	1.00	1.04	0.96	0.59	1.71	1.92	2.09	5.33
E6	0.69	0.73	1.07	1.02	0.96	1.00	0.92	0.57	1.64	1.84	2.00	5.11
E7	0.75	0.79	1.16	1.11	1.04	1.09	1.00	0.62	1.79	2.00	2.17	5.56
E8	1.21	1.29	1.88	1.80	1.69	1.76	1.62	1.00	2.89	3.24	3.52	9.00
E9	0.42	0.44	0.65	0.62	0.58	0.61	0.56	0.35	1.00	1.12	1.22	3.11
E10	0.37	0.40	0.58	0.56	0.52	0.54	0.50	0.31	0.89	1.00	1.09	2.78
E11	0.34	0.37	0.53	0.51	0.48	0.50	0.46	0.28	0.82	0.92	1.00	2.56
E12	0.13	0.14	0.21	0.20	0.19	0.20	0.18	0.11	0.32	0.36	0.39	1.00

Table 9:

Equipment weights with respect to production loss

production loss	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
E1	1.00	1.23	1.30	0.69	0.72	0.70	1.54	0.53	1.59	1.48	1.87	4.78
E2	0.81	1.00	1.06	0.56	0.58	0.57	1.25	0.43	1.30	1.21	1.52	3.89
E3	0.77	0.94	1.00	0.53	0.55	0.54	1.18	0.41	1.22	1.14	1.43	3.67
E4	1.44	1.77	1.88	1.00	1.03	1.02	2.21	0.77	2.30	2.14	2.70	6.89
E5	1.40	1.71	1.82	0.97	1.00	0.98	2.14	0.74	2.22	2.07	2.61	6.67
E6	1.42	1.74	1.85	0.98	1.02	1.00	2.18	0.75	2.26	2.10	2.65	6.78
E7	0.65	0.80	0.85	0.45	0.47	0.46	1.00	0.35	1.04	0.97	1.22	3.11
E8	1.88	2.31	2.45	1.31	1.35	1.33	2.89	1.00	3.00	2.79	3.52	9.00
E9	0.63	0.77	0.82	0.44	0.45	0.44	0.96	0.33	1.00	0.93	1.17	3.00
E10	0.67	0.83	0.88	0.47	0.48	0.48	1.04	0.36	1.07	1.00	1.26	3.22
E11	0.53	0.66	0.70	0.37	0.38	0.38	0.82	0.28	0.85	0.79	1.00	2.56
E12	0.21	0.26	0.27	0.15	0.15	0.15	0.32	0.11	0.33	0.31	0.39	1.00

After normalizing the data, the final weights for the equipment are shown in the table below:

Table 10:

Weight of the equipment

Equipment	Fire/Explosion	Effect on Environment	Effect on Personal	Production loss
E1	0.12	0.14	0.13	0.09
E2	0.11	0.14	0.12	0.07
E3	0.10	0.03	0.08	0.07
E4	0.08	0.07	0.09	0.13
E5	0.08	0.07	0.09	0.12
E6	0.07	0.05	0.09	0.12
E7	0.10	0.05	0.09	0.06
E8	0.14	0.20	0.15	0.16
E9	0.07	0.06	0.05	0.05
E10	0.08	0.11	0.05	0.06
E11	0.03	0.07	0.04	0.05
E12	0.02	0.02	0.02	0.02

3.4 Consistency calculation

Before going further into the calculation, it is necessary to check the judgement of the weights. The consistence ratio (CR) shows how consistent is the pair wise comparison. Two equations need to be used in order to find the consistency:

$$CI = \frac{\gamma_{max} - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

Where RI derived from Saaty’s book, in which the for each matrix number n, a corresponding index of consistency for random judgments. The table below shows the different index number.

Table 11:

RI index for given n

n	2	3	4	5	6	7	8	9	10
RI	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

If the Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, the subjective judgment need to be revised. In our case, the consistency ratio for the main criteria is equal to 0 as we have only two criteria. For the rest of pair wise comparison the highest consistency ratio was less than 5% which is acceptable and shows how consistent the judgement was.

3.5 Result & analysis

The final step is to multiply the weights. Note that the SHE risk criteria have to be multiplied by 0.67 and the production loss to be multiplied by 0.33. as an example:

$$E1 = 0.67[(0.37)(0.12) + (0.16)(0.14) + (0.47)(0.13)] + 0.33(0.09) = 0.1195$$

The table below summarize the final values for the equipment:

Table 12:

The final weight for the equipment

Equipment	final weight
E1	0.112
E2	0.104
E3	0.076
E4	0.095
E5	0.095
E6	0.092
E7	0.078
E8	0.157
E9	0.060
E10	0.065
E11	0.044
E12	0.017

The final weights show E8 as the most critical equipment then E1 and E2. For E1 and E2 the company ranking for it is A because they are a safety equipment. For E8, it is B criticality equipment, but still in the AHP analysis it comes before E1 and E2. For E12, D criticality equipment or run to fail, it comes at the end as the least critical equipment which is expected. E3 is A criticality equipment as the company ranking, but it is number 8 in the analysis after the all the B criticality equipment.

Assuming if the company needs to do maintenance for four equipment from the 12-equipment list analyzed before. The company will need to select the equipment based on the criticality and the prioritizing method they are using. The table below illustrate the options in the two methods.

Table 13:

Equipment prioritizing comparison between the two methods

	Company method	AHP
1	E1	E8
2	E2	E1
3	E3	E2
4	E4,E5,E6,E7,E8 (sharing the same criticality ranking B)	E4, E5 (further analysis with AHP can be done)

This result was shared with the two managers in the company. One is the manager of integrity and reliability department with 14-year experience. The second one is operation manager with 20-year experience. The respond was, that the prioritizing of the task is related mainly with the risk. In which each activity is going to be analyzed in the risk matrix and in which category it will be and what is the effect by not doing the activity which is the mitigation measure. When using the AHP the criteria are chosen based on the consequence of failure and the importance of the equipment. The debate will occur while discussing the weight for each equipment which can take a lot of time. In general, the risk matrix is a common tool in this industry and more conservative with safety.

The AHP can be used in less critical activities in the plant because it is mathematical module and needs less time to process

CHAPTER 4: CONCLUSION

The criticality ranking has been successfully made by using the AHP analysis. The final result shows somehow same as the company criticality. In the AHP there is a chance for discussion from time to time and whenever the need comes. In the company criticality ranking or the normal practice, the criticality been set since the commissioning of the plant and never reviewed again.

It is important in the AHP to choose participant from all the departments in the company. And it is better to do the analysis using meetings to share the knowledge, experience, thoughts and reach to strong justifications with the given weights.

As a conclusion, the AHP can be used in the industrial sector to find the criticality and to do the prioritization of the equipment. It can be used to prioritize the activities for the equipment in the facility in the case of having more than activity at the same time with same equipment criticality. The advantages in using AHP can be summarized as following:

1- Less processing time.
2- One general excel sheet can be utilized with all the data to perform the analysis.
3- There is a space to discuss.
4- Dynamic process not fixed criticality.
5- Always depends on the status of the plant.

Future studies can consider introducing new criteria on the analysis based on the needs. One idea is to merge the risk matrix with the AHP analysis to build a solid criticality classification method.

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APPENDIX

Copy of the Questioner

Department: Position:

First level criteria	SHE	Business
SHE	1	
Business		1

Equipment criticality:

#	Equipment	criticality	Fire/explosion	Effect on the environment	Effect on personal	Production loss
1	29PRV-xxx	A				
2	12VRV-xxx	A				
3	83-Vxxx	A				
4	12-Cxxx	B				
5	13-Vxxx	B				
6	16-Exxx	B				
7	19-Fxxx	B				
8	10-Xxxx	B				
9	10-Exxx	C				
10	12-Yxxx	C				
11	12-Txxx	C				
12	16-Sxxx	D				

SHE Criteria	Fire/explosion	Effect on the environment	Effect on personal
Fire/explosion	1		
Effect on the environment		1	
Effect on personal			1

Scale	Numerical rating	Reciprocal
Extremely importance	9	1/9
Very to extremely strongly importance	8	1/8
Very strongly importance	7	1/7
Strongly to very strongly importance	6	1/6
Strongly importance	5	1/5
Moderately to strongly importance	4	1/4
Moderately importance	3	1/3
Equally to moderately importance	2	1/2
Equally importance	1	1

AHP: Analytic hierarchy process