DEVELOPMENT OF A MANUFACTURING STRATEGY OF SPARE PARTS: A CASE STUDY

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ABSTRACT

Managing supplementary parts for plants and machines plays a major role in accomplishing the needed system availability in a cost-effective manner. Today's industrial demands require mature technology that is strong in terms of capital and bulk-production oriented. However, the idleness of these machines and equipment due to unavailability of spare parts is a major problem and barrier to effective systems availability. This study aims to develop an effective manufacturing strategy for spare parts. A case study was conducted at a General Water Desalination Establishment in Saudi Arabia to select the right strategy to reduce the total downtime and total maintenance costs of equipment. The results showed the importance of creating a production plan that suits an organization's ability to manage the supply chain for customers and ensure the company remains competitive within its market. Identification of critical spare parts of equipment for maintenance operations is one of the key decision-making activities to obtain lower downtime for equipment and inventory costs. Therefore, decision-makers should apply the best method and use accurate criteria to analyze and rank the spare parts based on criticality. The strategies proposed in the present study assure that these important parts are available for maintenance and repair of the plant and machinery when required at an optimum cost.

Keywords: supply chain; maintenance strategy; spare parts; multi-criteria decision making; Analytic Hierarchy Process.

1. Introduction

Supplementary parts refer to a component's requirements to manage the equipment and keep machines in good working order. If the replacement and repair work of the parts that are not in good working order is done on time, unavailability of the material will not be a problem. Supplementary components management plays an important role in the operation of production systems. This management is an important function in asset-intensive industries such as refineries, chemical plants, paper mills, and organizations owning and operating costly assets such as airlines, logistic companies, etc. (Bounou, El Barkany, & El Biyaali, 2017). Spare parts management in any organization is important since the maintenance department complains about the unavailability of the spare parts to meet their requirements while the finance department faces problems regarding increasingly locked-up capital in spare parts inventory (Zeng, Wang, & He 2012).

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Parts demand is created whenever a component fails or requires replacement. A company can face problems controlling and managing the availability of parts, and predicting and generating a valid forecast for the appropriate quantity of spare parts due to the uncertainty and variability of the consumption rate of spare parts (Bacchetti & Saccani, 2012). As a result of uncertainty, the failure of a component due to wearing out or other reasons cannot be predicted accurately. Another problem is the unavailability of spare parts in the market as a result of slow-moving items, obsolescence, and the complexity of controlling inventory provision. This all happens because of the large number and variety of spare parts needed for equipment in a plant. For example, the Water Desalination Establishment requires 288,841 spare parts with a yearly cost of 200 million Saudi riyal (SAR). It is also difficult to find the optimum quantity of available spare parts at the optimum cost, i.e., finding the appropriate inventory level and reorder quantity. For instance, primary financial hubs show an enormous figure of $700 billion dollars and 8% of the U.S. gross domestic product involved in the spare parts trade (Obstfeld & Rogoff, 2005).

The demand created by corrective and preventive maintenance is determined through spare parts inventory. The life for spare parts needs to be extended by appropriate reconditioning and repair techniques to allow for trading and making use of those spare parts as well as removing roadblocks involving inaccessibility in foreign exchange (Stoll et al., 2015). In one industry, the establishment of a spare parts bank has contributed significantly to reducing the overall holding inventory and stock costs of expensive spare parts. It would be a helpful practice for industries to establish spare parts banks and a suitable information system for the exchange of spares. Moreover, the application of computers to process spare parts information and operate an effective spare parts control system would be helpful for an organization to manage spare parts efficiently and effectively (Arts, 2014). Chekurov et al. (2018) verified the conceptual benefits of additive manufacturing (AM) in the supply chains of spare parts for the accelerative operation of industries. Moreover, this study presented a portfolio-level analysis to examine the effectiveness of AM compared to traditional manufacturing (TM). Heinen and Hoberg (2019) studied the significance of additive manufacturing in providing spare parts. To the author's knowledge, no study has formulated a pragmatic strategy for spare parts that aims to prevent production loss and accelerate the operation of equipment.

Therefore, the present study aims to provide an effective manufacturing strategy for spare parts by developing a methodology that could help minimize production loss and increase the operation of equipment. The study identified the control characteristics of spare parts and proposed a multi-criteria decision-making model to evaluate the criticality of spare parts. It also identified the logistic characteristics of spare parts and proposed a multi-criteria decision-making model to develop a manufacturing strategy for them. The paper adopts the methodology that has been applied to the General Establishment of Water Desalination in Saudi Arabia. The mixed method methodology, along with the case study, will increase the real-life implications of the proposed model by establishing specificity, demand, expiry date, delivery time, and item value.

2. Literature review

The non-availability of spare parts, particularly when required for repairs, results in great financial loss, especially for those industries with sophisticated technologies, aiming for mass and constant production. Consequently, spare parts management plays a significant role in attaining the anticipated equipment obtainability at a

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minimum cost (Turrini & Meissner, 2019). The process of spare parts management takes place by determining peculiar characteristics that require a lot of work. These characteristics involve sporadic demand patterns, sequences of zero demand observations, and difficulty in demand forecast (Hu et al., 2018). Taking this complexity into consideration, additive manufacturing is adopted as an effective spare parts supply strategy for effective decision-making and quantitative analysis (Zhang et al., 2018). Therefore, Zhang et al. (2018) conducted research wherein a quantitative performance model was formulated for a spare parts supply chain and studied in an interesting area of research where there is scant literature available. However, the AM model is not cost-effective and characterized by the same cost attributes as the conventional methods (Zhang et al., 2018). Another recent study by Helo and Hao (2021) propounded the idea of using artificial intelligence (AI) to forecast inventory requirements in supply chain management. The study explored different areas where the use of AI has produced desired results in inventory management or supply management, such as systems to determine supplier selection/partner selection, reducing supplier risk, predicting credit risks of small and medium firms, supply chain finance, and order-picking systems. Moreover, the study asserted that there is an increasing role of AI as an intelligent assistant for operational procurement, spare part demand forecasting, quality control, inventory control, automated quality control, production optimization, capacity improvement, lead time reduction, monitoring, predicting the conditions of the cutting tool and bearing and fraud detection and prevention.

Furthermore, Baryannis (2019) revealed that a supply chain management (SCM) approach is considered AI-based if it satisfies both of the following characteristics: it can autonomously decide on a course of action that leads to success in SCM-related objectives and can do so under a partially unknown supply chain environment. Simply put, AI-based SCM can make decisions based on self-learning in any scenario (Helo & Hao, 2021). Soleimani (2018) points out that AI techniques can be implemented in four identified attributes in SCM: optimization, prediction, modeling and simulation, and decision support. Choi et al. (2018) summarized six areas in which big data and various machine learning methods are applied in the operation management field including forecasting, inventory management, revenue management and marketing, transportation, supply chain management, and risk analysis. These areas are also related to AI.

Spare parts management is often seen as a special case of general inventory management with some features that are particularly difficult. Important spare parts have the following four characteristics. First, the intermittent demand pattern for spare parts is common. They are characterized by sequences of zero-demand observations interspersed with occasional non-zero demands (Duran, Roda, & Macchi, 2016). Spare parts management is likely to provide refurbished spare parts for maintenance purposes and ensure the availability of equipment during its life cycle at optimum cost, at the time of its need (Sarmah & Moharana, 2015). Spare parts are beneficial for reducing the consequences of downtime of equipment and are a prerequisite for achieving the desired equipment availability with cost-effectiveness (Hu et al., 2018).

According to industry estimates, various producers detect that the perimeter for services and production machinery can take up to 40% of the total area covered; however, the perimeter for completed goods can take up to 13% of the total area. Moreover, spare parts need to be of the right quality to ensure effective management. Figure 1 illustrates the balance between spare parts cost and availability (Houtum & Kranenburg, 2015). This study is novel in that it uses the Analytic Hierarchy Process

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to provide a framework for the General Establishment of Water Desalination in Saudi Arabia so that a working strategy could be developed for the management of spare parts.

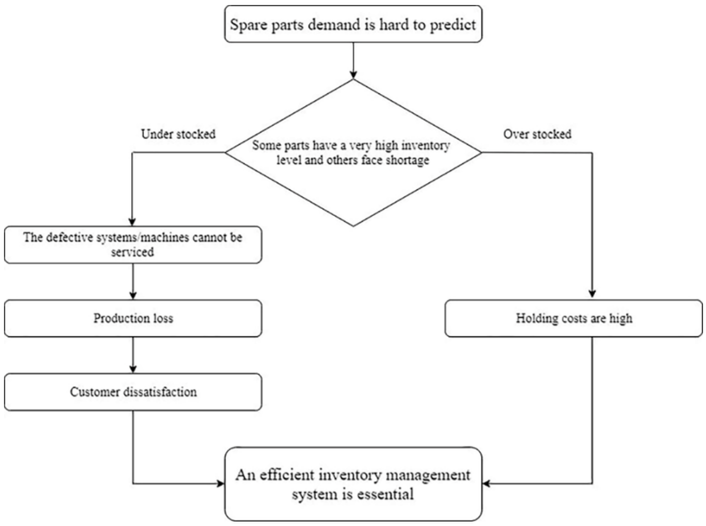

Figure 1 Spare parts cost versus availability

The key questions in any spare parts management that affect equipment availability include:

- Which items are needed as spare parts?
- Which items should be put in stock?
- When should the items be (re)ordered?
- How many items should be (re)ordered?

The requirement for supplementary parts is majorly dependent on the results of obstructive and predictive sustentation activities and is usually based on Mean Time to Failures (MTTF) calculations. There is a requirement to maintain buffer inventory for the management of sudden break-downs due to incorrect operation or lack of success executing a routine maintenance activity leading to demand with no conveyable predictable reasons. The requirement of the supplementary parts is based on the machine's lifecycle and is represented by the inverted bathtub curve (Huiskonen, 2001). Utilization/consumption data for spare parts make it difficult to create a statistically legitimate assumption of the rate at which supplementary parts are needed. Management of the inventory is a difficult task because of modifications in the existing common parts. Spare parts are often produced locally, and due to the expansion of local manufacturers, error inspection relies on various elements. Organizing numerous sources of stock for the same part creates a need for greater diligence and attention to service maintenance (Huiskonen, 2001).

Peres and Noyes (2006) discussed the concept of spare part manufacturing on request and in a short time. They showed how the new techniques of prototyping and direct manufacturing combined with the principles of e-maintenance could be a relevant response to the problem of spare part management of isolated systems. The study also investigated the idea of manufacturing the parts required for the overhaul and repair of the equipment on the spot and on demand. In addition, they considered rapid prototyping techniques whose inputs are raw material and numerical date corresponding to the part to be made (Peres & Noyes, 2006). These industrial

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applications have demonstrated the feasibility of the concept. The study concluded that it is possible to efficiently manufacture complex parts under operating conditions as compared to the traditional solutions of spare parts procurement. The advancements made in the rapid manufacturing technological field should increase the possibility of generalization of the concept of e-logistic support in the medium term (Das et al., 2020).

According to Kim and Park (2008), a firm's strategy should be to determine its product price, and warranty period, and plan the spare parts manufacturing to maximize its profit. This approach also helps fulfill the firm's commitment to continuously providing the customer with the key part over the relevant decision time period, i.e., the product's life cycle plus its end-of-life service (warranty) period. The study discussed how to decide on optimal pricing and warranty when the product life cycle is finite and the company is obliged to provide after-sales services to customers for an extended period after the current product is no longer produced.

According to Wu and Hsu (2008), one approach to reduce the total operating cost of a spare parts logistics system is by properly designing the BOM (Bill of Material) configuration. A spare part may have multiple vendors. Parts supplied by different vendors may vary in failure rate and price, i.e., the higher the failure rate, the lower the price. Their approach can calculate the optimum inventory policy and its associated total logistics cost. In addition, a genetic algorithm - neural network was developed to quickly find a near-optimal BOM configuration.

According to Venkataraman (2007), the inventory analyses carried out based on different characteristics of the spare parts help the company establish suitable policies for selective control. The basic characteristics of spare parts include annual consumption value, criticality, lead time, unit cost, and frequency of use. Driessen et al. (2015) discussed the effect of four control characteristics of the maintenance of spare parts, i.e., criticality, specificity, demand pattern, and value of parts on logistics system elements. The demand for spare parts often comes from another source of failure. For instance, the failure of a key on a gear shaft that is mediatory will need to be repaired or replaced as well as other parts like gears for proper function of the vehicle or machine. Similarly, the need for supplementary parts is necessary to maintain and extend the device's life cycle. The absence of spare parts influences the process negatively and leads directly to expensive machine downtime. Therefore, companies tend to use AM to identify and resolve challenges related to spare parts management (Chaudhuri et al., 2021). Another study by Kuzu (2020) used the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to sort out maintenance planning problems for equipment with high criticality levels in the hydroelectric power plants for meeting the quintile of Turkey's energy demand as of the end of 2018. The study used the Analytical Hierarchy Process (AHP) to determine the criticality levels of the equipment of the power plant. The maintenance plan was implemented for two years and reached its goals (Kuzu, 2020). Considering the above-mentioned literature, the present study aims to focus on the manufacturing strategy of spare parts. There are many challenges associated with the production of spare parts through traditional supply chains (Heinen & Hoberg, 2019). The demand for spare parts is unpredictable; and yet, manufacturers need to be sure about the availability of spare parts for their customers. Anticipating the demands of customers and creating a safe stock of spare parts is likely to require high inventory needs and favor shorter delivery times. Large manufacturers use multi-level distribution networks rather than directly delivering a product to the customer (Dekker et al., 2013).

2.1. Case study

A case study was conducted at one of the General Establishments of Water Desalination in Saudi Arabia. It is a Saudi government establishment dealing with the desalination of seawater, power production and delivery of fresh water produced for different regions in the country. It was established in 1928 in Jeddah to serve fresh water to the convoys of pilgrims and Jeddah. Today, Saudi Arabia is considered one of the world's largest producers of desalinated seawater. There are 15 desalination stations on the east coast and west coast of Saudi Arabia that produce 3 million cubic meters of water per day and 1,270,800 megawatts of electricity per month (Baig et al., 2020).

3. Materials and methods

3.1. Review of the AHP method

The Analytic Hierarchy Process (AHP) method provides a comprehensive structure for combining intuitive rational and irrational values during the decision-making process through a pairwise comparison approach. The structure of this technique breaks down big problems into easily manageable small problems by solving complex decisions, and finds solutions for the complex processes (Kahraman, Oztaysi & Cevik Onar, 2020; Abdel Basset et al., 2017). In addition, the AHP allows decision-makers to assess the consistency of the decision-making process by applying a consistency ratio. After the inflation crisis and pandemic, AHP concepts used in industries and business models have been expanded to adapt to the transformation created by these events. This transformation will affect the structure and the strategies of the decision-making process (Traneva and Tranev, 2022; Saaty, 2016). Many researchers have used the AHP for decision-making in numerous sectors, i.e., economic issues, policy formulation, and urban management, prioritizing investments in the chemical industry, formulating urban water supply systems, selecting material suppliers, investigating environmental impact, and environmental impacts of manufacturing (Rawal, 2021). However, Yuen (2022) argued that the AHP might comprise misapplications; thus, it is necessary to use the paired interval scale when assessing pairwise comparisons when choosing competitive alternatives in decision-making.

The main steps of the AHP method are as follows (Ali, 2022):

Step 1. Define the problem. The problem to be analyzed is selected from those that are important or complex enough to be analyzed. This choice itself can cause complex problems that require specific analysis. When defining and selecting a problem, it is important to articulate the assumptions and perspectives on which the decision was made.

Step 2. Define objectives by considering all actors, goals, and outcomes.

Step 3. Identify criteria and subcriteria.

Step 4. Configure the problem with different levels of hierarchy that represent a goal, criteria, subcriteria, and a set of alternatives. This structure builds decision-making goals from the top, then builds goals from a broader perspective from the middle level (criteria) to the lowest level (usually a series of decisions). Conceptually, once the main goal or objective is defined, a solution can be sought to the problem accessed through either a top-down process (criteria to the alternative) or a bottom-up process (alternative to criterion). The model needs to be built in such a way that relevant criteria and alternatives can be

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identified. The decision hierarchy should be large enough to include the main concerns of the decision maker and small enough to allow timely changes. In this step, decision-makers need to eliminate alternatives that do not meet the criteria that are considered unrealistic or irrelevant.

Step 5. Compare each element at the corresponding level and adjust on a numerical scale. This requires n(n-1)/2 comparisons. Here, n is the number of elements, taking into account that the diagonal elements are equal or "1" and the other elements are simply the reciprocals of the previous comparison.

Step 6. Perform calculations to determine the maximum Eigen value, consistency index (CI), consistency ratio (CR), and normalized values for the criteria and/or sub criteria and alternatives.

Step 7. If the maximum Eigen value, CI, and CR are sufficient, the decision is made based on the normalized values. Otherwise, the procedure is repeated until these values are within the desired range.

Various types of approaches are considered by aggregating the opinions of groups of people in applying the AHP method in the group decision-making process (Aguarón et al., 2022). First, individual evaluations are aggregated using the weighted geometric mean method. Then, the individual priorities are aggregated. In this study, we chose to aggregate individual evaluations using the weighted geometric mean method. The methodology proposed in this study consists of four parts that provide an effective spare parts manufacturing strategy. The main reason for choosing the aggregate of individual evaluations by the weighted geometric mean method is because if the alternative local priority is changed, normalization criteria also change; the alternative global priority is derived using weighted arithmetic mean aggregation, which is different if the ranking obtained by weighted geometric mean aggregation does not depend on normalization which may lead to change in rankings (Krejčí & Stoklasa, 2018). In addition, the aggregation of individual judgments by weighted geometric mean is more consistent compared to other methods, and this advantage is important for group decision-making (Lami, & Todella, 2023).

3.2. Identify control characteristics of spare parts

The operation control characteristics of the maintenance spare parts are as follows: criticality, specificity, demand pattern, and value of the spare parts. The criticality of spare parts is probably the first characteristic expressed by spare parts logistics practitioners. Item criticality is usually expressed in terms of the impact of defects on production, safety, and the environment. Zhang and Zeng (2017) identified two types of criticalities: process and control. Criticality of spare parts refers to the consequences of failure of the parts in the process. Alternatives that are not readily available are called process criticality. However, other aspects of criticality are linked to the ability to control the situation. The proposed possibilities are part of the criticality of so-called control, including lead time, supplier availability, and failure predictability (Yang et al., 2022). The factors that affect the criticality of spare parts are:

- Specificity of a spare part (C1): A wide spectrum of spare parts are required by many users; however, a certain number of parts are specifically tailored and used by only one party. The availability is usually good for the standard parts; therefore, the criticality of a spare part is lower. However, the criticality of a spare part is higher as the availability is lower for non-standard parts.
- Status of availability of the production facility (C2): The condition when the original part has failed and a spare part is required is as follows:
    - Spare parts are less critical if alternative manufacturing facilities are available.

- Spare parts are less critical if alternative manufacturing facilities are available and appropriate changes have been made to the machine or process.
- Spare parts can become more critical if there are no alternative manufacturing facilities.

- Lead-time of procurement (C3): The difficulty of procuring spare parts is related to the procurement lead time. It is more critical if the lead time is long and vice versa.
- Reparability character (C4): If spare parts cannot be repaired or if the repair time is long, spare parts management becomes difficult and spare parts become more critical.
- Stage of the life cycle (C5): When spare parts are in the initial or decay phase, it becomes more difficult and more critical to get spare parts in a short time period.
- Supply market (C6): There is less criticality if spare parts are always available from multiple suppliers. However, it can be of high criticality if spare parts are not readily available from multiple suppliers.

3.3. Criticality model

The AHP is used as a multi-criteria decision model to identify critical spare parts relevant factors that determine relative importance (Kuzu, 2020). Expert Choice software is used to perform the necessary calculations. The overall objective of this model is to determine the criticality of spare parts based on three decision alternatives: low, moderate, and high criticality. The proposed methodology is applied to the General Establishment of Water Desalination in Saudi Arabia. The spare parts considered are two pump spare parts. The qualitative and quantitative criteria that affect the criticality class of spare parts were established based on group discussions and detailed data questionnaires. Face-to-face interviews were conducted to obtain detailed information on the selected criteria and alternatives.

Given the specificity of a spare part, there is a broad spectrum of spare parts available which are widely used by many parties. In contrast, some are required by a minimum number of users for a particular use only. For standard parts, if the availability is usually good, the criticality of a spare part is less. For non-standard parts, the availability is less, so the criticality of a spare part is more. Concerning lead time for procurement, if the lead time is long, it will increase criticality. If the lead time is less, criticality is less. Therefore, five criteria have been established to perform the following analysis (Figure 2).

- Specificity (standard part [St], special part [Sp])
- Demand (Cheap [C], Moderate [M], Expensive [E])
- Expiry Date (outdated [Ot], 1-2 years [1-2], More than 2 years [>2])
- Lead /Delivery Time (long [Ln], average [Ag], short [Sh])
- Item value (Cheap [C], Moderate [M], Expensive [E])

3.4. Logistics characteristics

Once the operational control characteristics and the relative importance of criticality have been identified, the AHP can be used to identify the logistics characteristics. Molenaers et al. (2012) proposed a multi-criteria model to identify logistics characteristics. Table 1 defines the AHP rating matrix for the three subcriteria. The hierarchy in Figure 3 shows the relative weights of the criteria as well as the alternative ratings. The criterion replenishment time received the maximum weight

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(0.669). This parameter was considered the most important logistics attribute for the criticality of the part. The relative weights of the number of potential suppliers and the availability of specifications were 0.064 and 0.267, respectively. Composite weights are calculated by multiplying the relative weights of an attribute by an alternative weight. Based on the combined weights, the upper and lower limits of the choices of logistics characteristics are shown in Table 2. Each possible combination of logistic factors was calculated into a single score that simply fits into one of the three classes of logistic characteristic alternatives by calculating the boundaries of each alternative class.

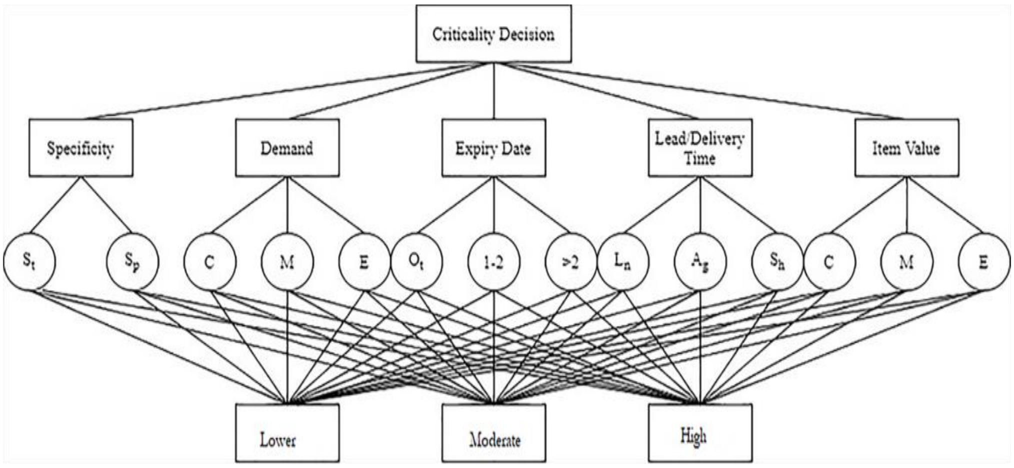

Figure 2 Hierarchy structure of criticality

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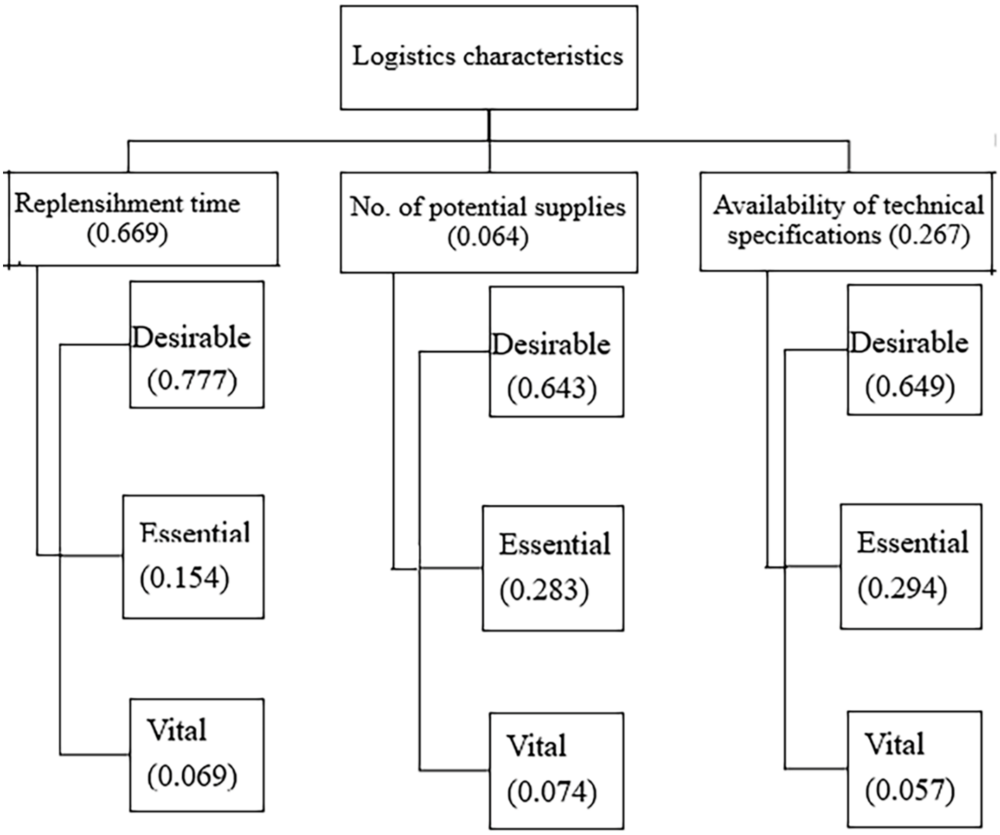

Figure 3 Hierarchy structure of logistics characteristics

Table 1
AHP judgment matrix for subcriteria

	Replenishment time	No. of potential suppliers	Technical specifications	Normalized eigenvector
Replenishment time	1.000	9.000	3.000	0.669
No. of potential suppliers	0.111	1.000	0.200	0.064
Technical specifications	0.333	5.000	1.000	0.267

Table 2
Composite weight for logistics characteristics

Criteria	Composite weights of alternatives		
	Vital	Essential	Desirable
Replenishment time	0.046	0.104	0.519
No. of potential suppliers	0.005	0.018	0.041
Availability of technical specifications	0.015	0.079	0.173
Logistics characteristics	0.066 – 0.260	0.261 – 0.602	0.603 – 0.734

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3.5. Manufacturing strategy model

Most companies in machinery and plant engineering lack decision support in terms of cost quantification of various spare parts. This makes it difficult to make effective decisions without any allocation strategy to help choose where to efficiently use the technology. The technical aspect of AM tends to produce innovation and customize the product according to the need and it is used in the automotive, healthcare, aviation and engineering industries (Ott et al., 2019; Hettiarachchi, Brandenburg, & Seuring, 2022). Achillas et al. (2015) proposed a framework for selecting an effective portfolio of production strategies with AM. In addition, Abattouy, Ouardouz, and Azzouzi (2022) developed a cost model to estimate the total cost per part for Selective Laser Melting (SLM). In this study, the preliminary design was prepared for the engineers to study profits in the cost estimation. The parameters of the products were studied to investigate the influencing methodologies of the SLM. However, the study concluded that adopting combined methodologies for measuring AM and spare part allocation produces limited results. Furthermore, Sgarbossa et al. (2021) developed a three-phase workshop concept, where potential spare parts were identified through an Assessment-and Decision-Phase. In this study, six criteria were established for the same two spare parts used before and after the series of interviews to carry out the analysis. The six criteria were spare part criticality, order quantity, materials, manufacturing costs, technical information, and manufacturing quality. Therefore, the criteria for a competitive manufacturing strategy and its measures are as follows:

- Criticality, (Cheap [C], Moderate [M], Expensive [E])
- Order Quantity (Cheap [C], Moderate [M], Expensive [E])
- Material (special [Sp], standard [St])
- Manufacturing Cost (Cheap [C], Moderate [M], Expensive [E])
- Technical Information (available [Av], non-available [Na])
- Manufacturing Quality (Cheap [C], Moderate [M], Expensive [E])

Spare parts manufacturing strategies can be calculated after identifying operational control characteristics, the relative importance of criticality, and the logistic characteristics of spare parts. The next step is to use the AHP as a multi-criteria decision model and Expert Choice software to determine the optimal manufacturing strategy. The overall objective of this model is to identify spare parts manufacturing decisions based on the following four decision alternatives: produce locally, purchase locally, produce overseas, and purchase overseas (Figure 4).

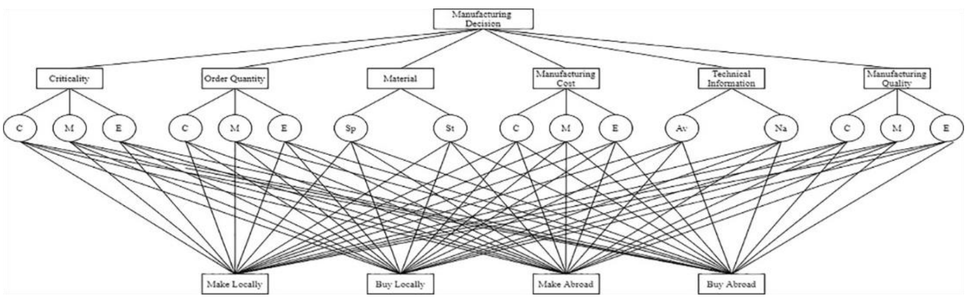

Figure 4 Hierarchy structure of manufacturing decision

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4. Results and discussion

Desalination plants require a large number of spare parts (about 300,000 items) in stock, 65% are classified as mechanical parts (mainly pump spare parts and small parts valves, leak prevention items, and filters), 25% are electrical components, and 10% are spare parts for instrumentation and control. They are stored in a local camp inside the factory. These spare parts are sourced from local distributors and manufacturers. Figures 5-9 show some of the spare parts used at this station. Two spare parts were selected by the General Establishment of Water Desalination to identify manufacturing strategies using the methodology proposed in this study.

Figure 5 Fan cover

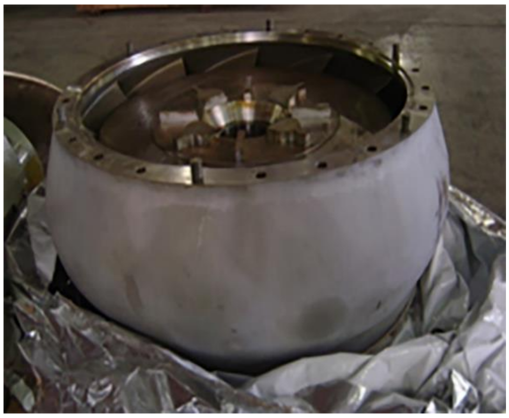

Figure 6 Flange

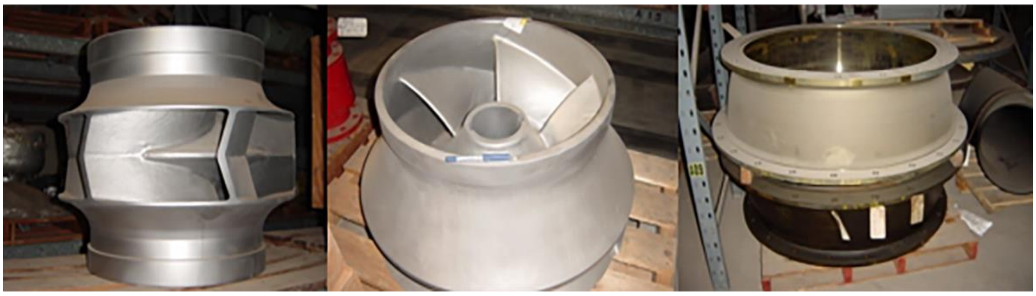

Figure 7 Pump spare parts

Figure 8 Water boiler

Figure 9 Push

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4.1. First spare part

The overall weight of each alternative can be calculated after creating two hierarchies for the first spare part selected. This can be done after performing all the required pairwise comparisons from the top level to the bottom level of the hierarchy using the Expert Choice software. Figure 10 shows a comparison of the numerical assessment pairwise and the relative importance of the lead time/delivery time of the first spare. The Expert Choice model has objectives (criteria) in the tree view panel on the left side and the alternatives are in the alternative panel on the right side of the sheet. Figure 11 shows the overall weight of the three decision-making alternatives of criticality (high = 74%, moderate = 20.3%, low = 5.8%). Sensitivity analyses from the objective node show the sensitivity of the alternatives with respect to all the objectives below the goal. When performing a sensitivity analysis, the priorities of the objectives may be varied to observe how the priorities of the alternatives change. There are five types of sensitivity analysis as follows: Dynamic, Performance, Gradient, Head-to-Head and Two-Dimensional (2D Plot). Four types of sensitivity analyses can be opened at once as shown in Figure 12 or each one can be opened separately. Figure 12, on the other hand, shows a sensitivity analysis for the same part using Expert Choice to determine the criticality. However, Figure 13 shows a pairwise graph assessment that compares the relative importance in terms of materials. Figure 14 shows the overall weight of the four decision alternatives for determining the first spare part (make locally = 21.1%, buy locally = 22.8%, make overseas = 35.1%, and buy overseas = 21.0%). In contrast, Figure 15 shows a sensitivity analysis using Expert Choice to make the first spare part manufacturing decision. The first spare part is of high criticality and its manufacturing strategy is to make it overseas based on the case study analysis.

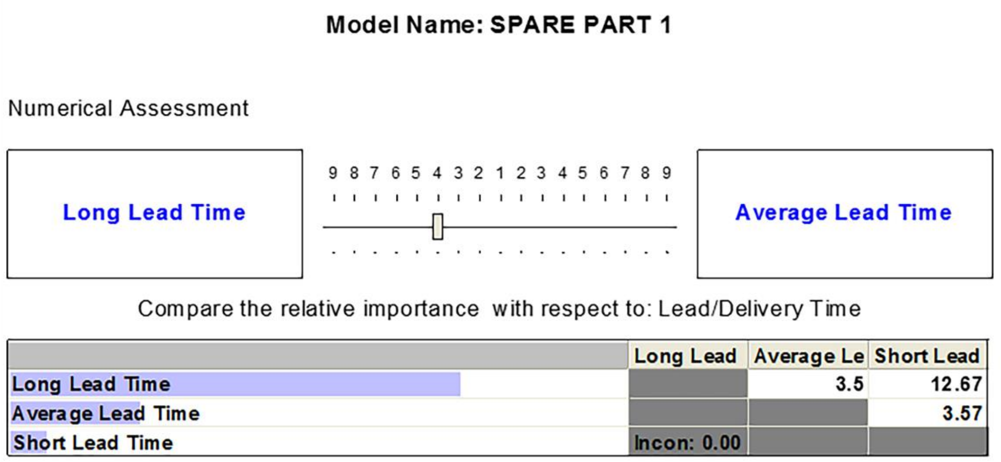

Figure 10 Numerical pairwise comparison of lead/delivery time criterion

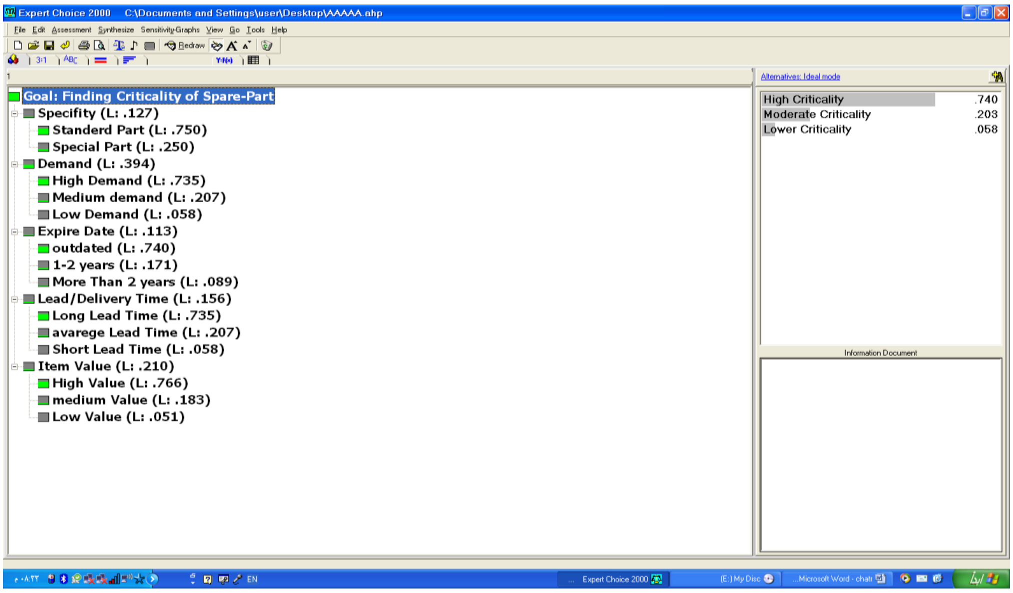

Figure 11 Overall weight of criticality decision alternatives

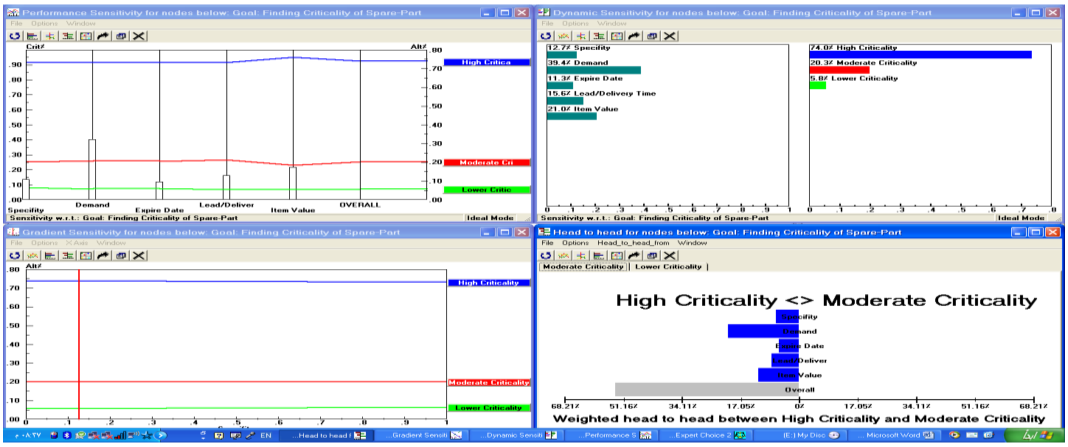

Figure 12 Sensitivity analysis of criticality decision

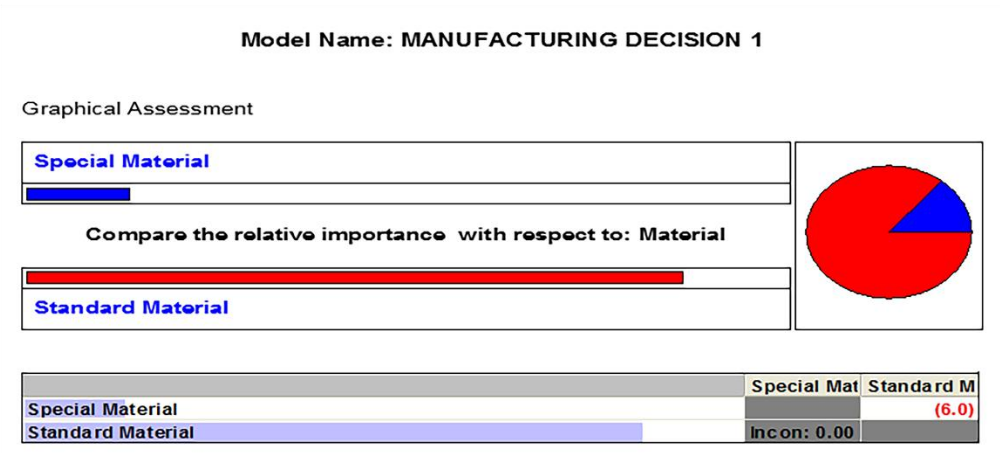

Figure 13 Graphical pairwise comparison of material criterion

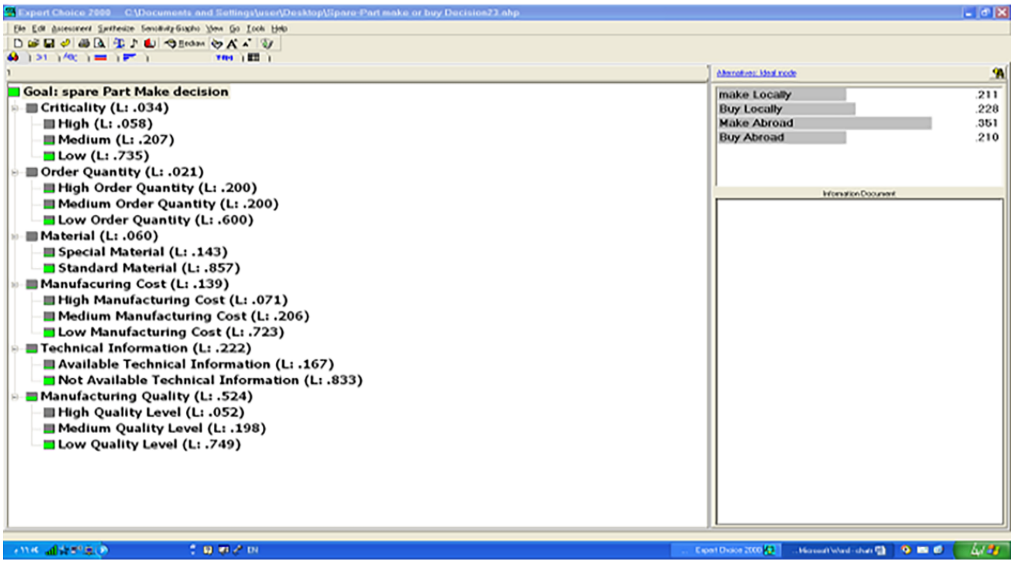

Figure 14 Overall weight of manufacturing decision alternatives

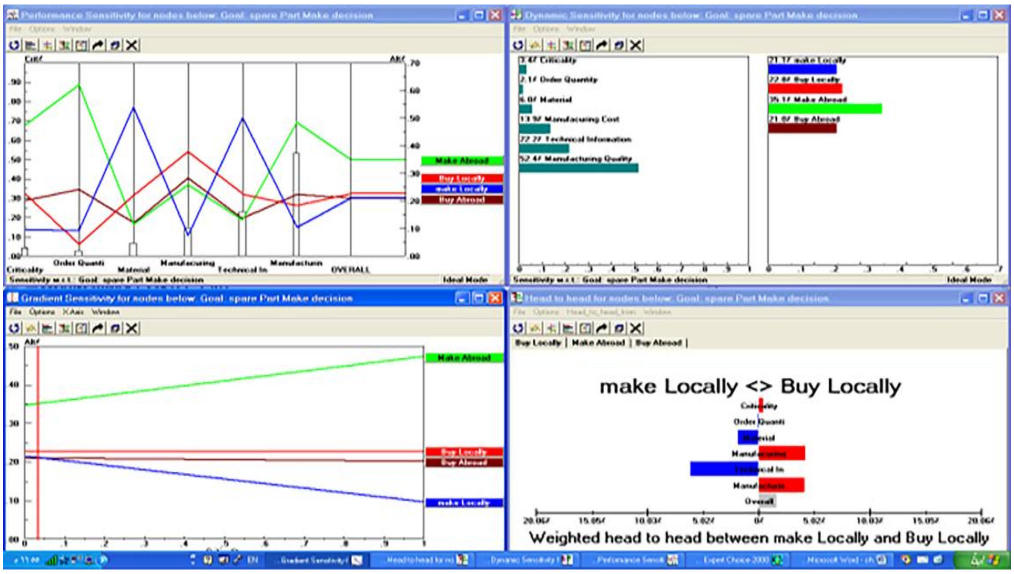

Figure 15 Sensitivity analysis of manufacturing decision

4.2. Second spare part

The overall weight of each alternative can be calculated after creating two hierarchies for the second spare part selected. This can be done after performing all the required pairwise comparisons from the top level to the bottom level of the hierarchy using the Expert Choice software. Figure 16 shows a comparison of the numerical assessment pairwise and the relative importance of the expiration date of the first spare part. Figure 17 shows the overall weight of the three decision-making alternatives of criticality (high = 14.5%, moderate = 29.4%, low = 56.1%). Figure 18, on the other hand, shows a sensitivity analysis for the same part using Expert Choice to determine the criticality. However, Figure 19 shows a pairwise comparison of the relative importance in terms of high demand. Figure 20 shows the overall weight of the four decision alternatives for determining the second spare part (make locally = 36.1%, buy locally = 30.5%, make overseas = 18.8%, and buy overseas = 14.8%). In contrast, Figure 21 shows a sensitivity analysis using Expert Choice to make the second spare part manufacturing decision. The second spare part is of low criticality and its manufacturing strategy is to make it locally based on the case study analysis.

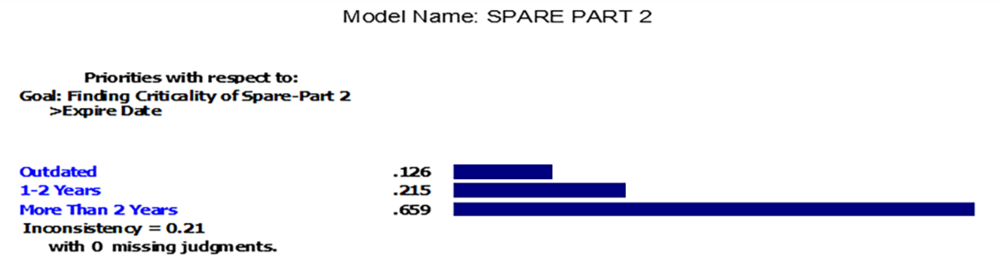

Figure 16 Relative weights concerning the expiration date

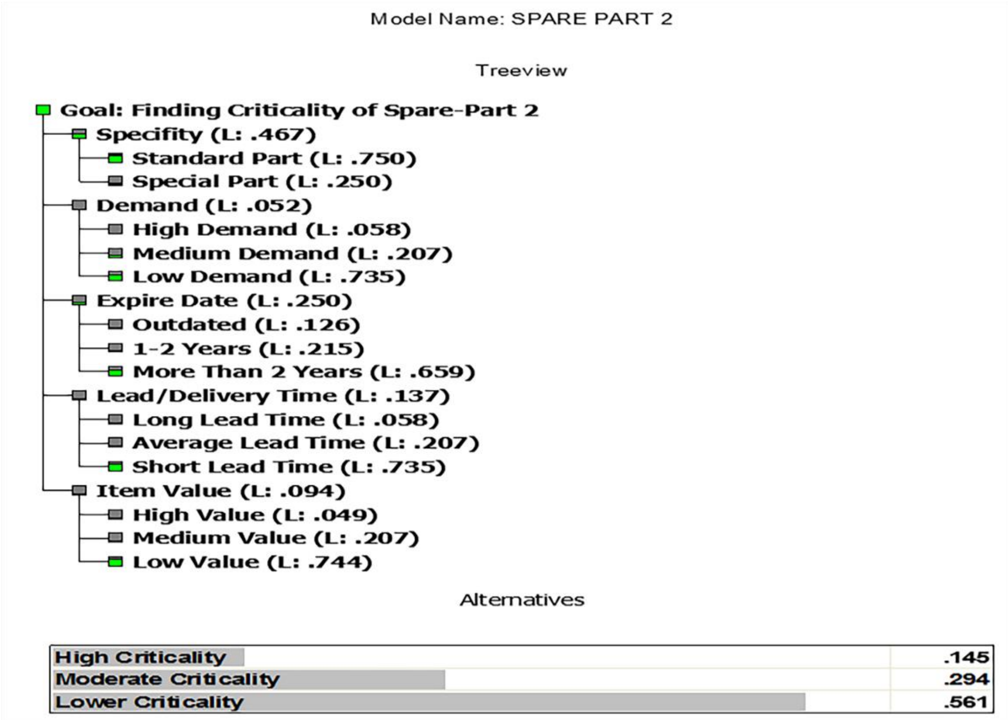

Figure 17 Overall weight of criticality decision alternatives

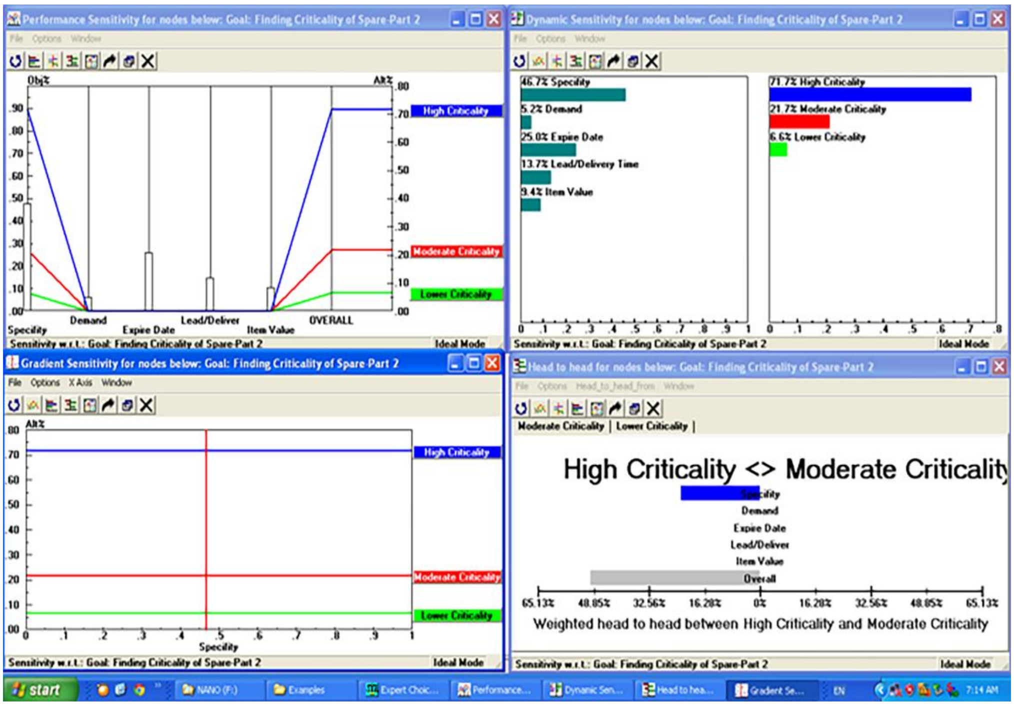

Figure 18 Sensitivity analysis of criticality decision

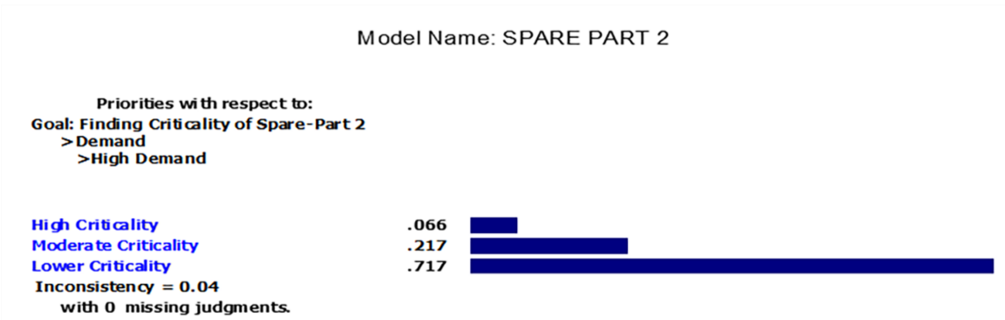

Figure 19 Relative weights concerning high demand

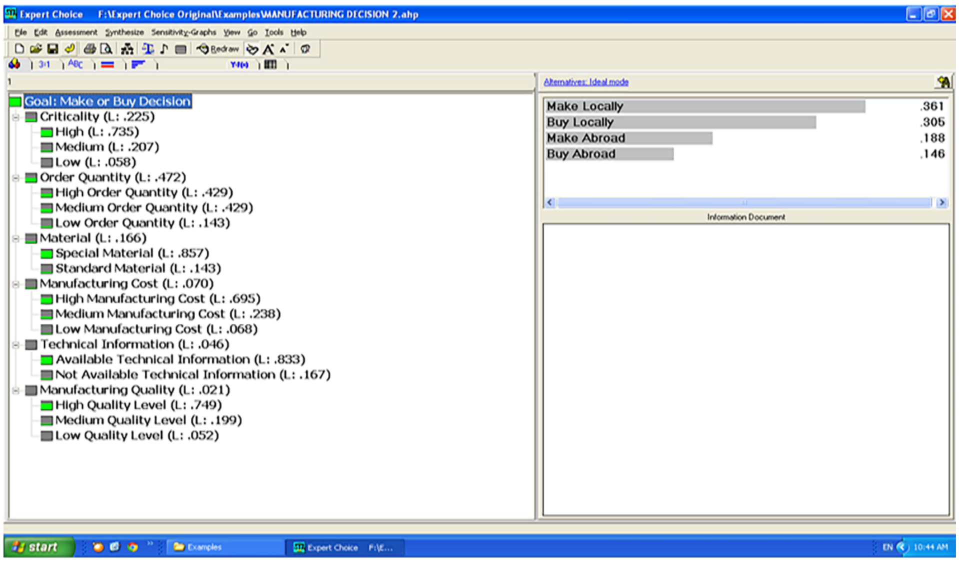

Figure 20 Overall weight of manufacturing decision alternatives

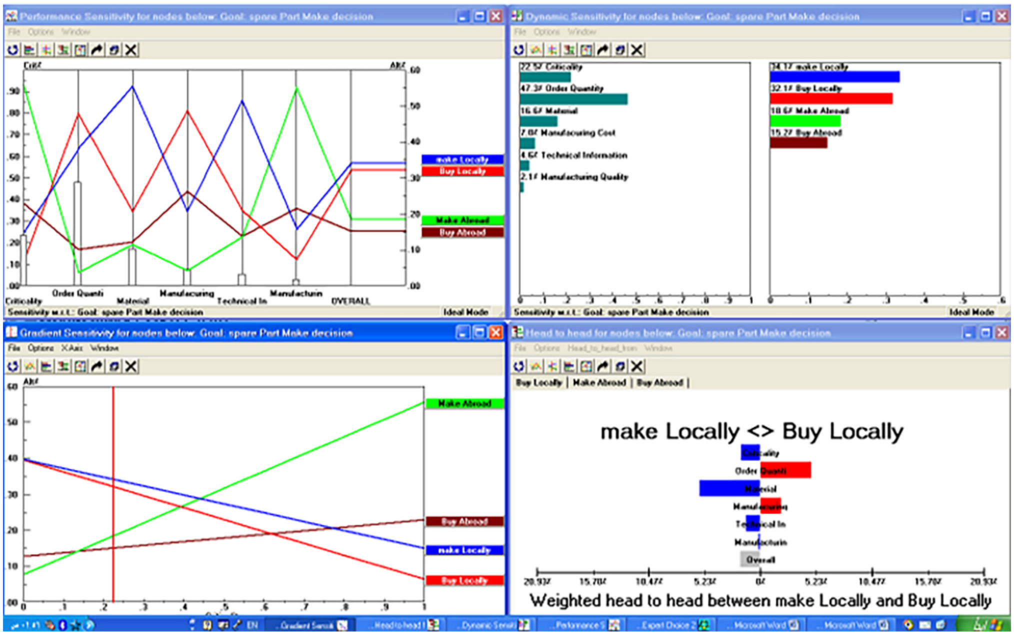

Figure 21 Sensitivity analysis of manufacturing decision

Spare parts manufacturing strategies play an important role in the success of certain businesses, as the development of manufacturing strategies is essential to maintain the supply chain and to be competitive in the market. These findings are similar to Tusar and Sarker (2022) who presented a model based on determinant factors and the applicability of the models. The study used the computerized maintenance management system software for optimizing maintenance spare parts to be used in reordering processes. Moreover, Rosita et al. (2020) also proposed a system that performs timely calculations, thus, minimizing the cost of equipment downtime through the successful implementation of a CMMS-based inventory management system (Rosita et al., 2020).

This study is a beneficial addition to the literature in the field of mechanics because it will be helpful for machinery industries to work on the spare parts of water desalination projects. Water desalination is an important component in the betterment of the country's economy. Since Saudi Arabia is considered a developed country, developing a drinking water usage system is essential for the country. This study helps strengthen the backbone of the water desalination industry. This study implemented a computerized system to maintain a record of the 300,000 spare parts in a more organized form in order to develop the base of the national industry which plays a major role in the country's economy.

5. Study limitations

The study has some limitations involving the implementation of AI with the models and concept of the desalination industries' spare parts and tools. Research related to these projects needs to be funded at the government level. The failure of the components needs research, but due to space consumption in terms of huge parameters of the area required to process the work and erratic management of the data this study is not getting the necessary support. The concept of this study needs further investigation in developed countries that are struggling with the water desalination process. The practically and functionally of the AI model in these projects needs to be studied because it is only discussed on a theoretical level here.

The implemented strategies could be applicable in every size industry to support the economy of the country.

6. Conclusions

This study proposed a methodology for developing an effective spare parts manufacturing strategy using the Analytic Hierarchy Process (AHP). A case study was conducted at one of Saudi Arabia's General Establishment of Water Desalination sites to develop a manufacturing strategy for specific spare parts and validate the use of the proposed methodology. The findings show that identifying critical equipment spare parts for maintenance work is important to reduce equipment downtime and inventory costs. This goal can be achieved by analyzing and ranking spare parts based on criticality, using the best methods and accurate criteria. Future research should aim to explore other control characteristics of spare parts using the Analytical Network Process (ANP) approach to investigate the interdependencies between competing priorities. The study needs collaboration between industry and academics to develop understanding of the rate at which the spare part production and availability increases or decreases. Further study can be done on quantitative methods to measure the accuracy of the spare parts used for the industry and their proper maintenance. The new strategies should be implemented in national and local industries to stabilize the economy. Industry can improve profits and production by reducing the disadvantages and major losses resulting from unavailable spare parts. The water desalination industry is not the only industry where this method can be useful; these advanced models and strategies could be implemented in other industries such as petrochemical, oil, and fertilizers, etc. These models should be recognized by the government and approval given to run these projects as well as funding provided to investigate better strategies.

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