Decision Support System for Spare Parts Warehousing

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ABSTRACT: Spare parts warehousing decision-making plays an important role in today's manufacturing industry as it derives an optimum inventory policy for the organizations. Previous research on spare parts warehousing decision-making did not deal with the problem holistically considering all the subjective and objective criteria of operational and strategic needs of the manufacturing companies in the process industry. This study reviews current relevant literature and develops a conceptual framework (an integrated group decision support system) for selecting the most effective warehousing option for the process industry using the analytic hierarchy process (AHP). The framework has been applied to a multinational cement manufacturing company in the UK. Three site visits, eight formal interviews, and several discussions have been undertaken with personnel of the organization, many of which have more than 20 years of experience, in order to apply the proposed decision support system (DSS). Subsequently, the DSS has been validated through a questionnaire survey in order to establish its usefulness, effectiveness for warehousing decision-making, and the possibility of adoption. The proposed DSS is an integrated framework for selecting the best warehousing option for business excellence in any manufacturing organization.

KEY WORDS: Analytical hierarchy process, decision support system, and outsourcing

Warehousing facility decisions play a major role in the overall management of manufacturing supply chains of any industry. In order to remain competitive in the market, organizations are emphasizing more on lean logistics. As organizations attempt to strike a balance between responsiveness to the customers and cost reduction in operations in terms of efficiency, optimized warehousing decision-making becomes more and more critical [11]. This is because a large number of warehouses increase the level of customer service against higher expenditure on logistics, warehousing and inventory [7]. There are several factors like supply chain strategy, regional facility configuration, desirable site and location choices that need to be considered for such a design.

In the manufacturing industry, the financial losses of unplanned production shutdowns are immense compared to the price of spare parts. Therefore, the organizations keep a large inventory of spare parts at their own warehouses to be able to react immediately to unforeseen problems in the case of high spares delivery lead-time [2]. Also as the manufacturing companies have their warehouses for finished products, the in house warehouses for spare parts do not cost them much in terms of infrastructural set ups and operations. However companies that process materials like cement often despatch the bulk finished product immediately after processing to the customers without requirement of storage. This makes the spare part warehousing for such process organizations more critical as the companies do not have finished goods warehouses and thus need to invest solely on spare parts warehouses and bear the ongoing operating cost. This makes them more inclined towards outsourcing warehousing to third party logistics providers [18].

In the process industry, organizations find it critical to strike a balance between responsiveness and cost in terms of spare part warehousing. On the one-hand, spare parts close to plants give better responsiveness with respect to minimum equipment downtime. On the other hand, this decentralized system of warehousing incurs huge amounts of operating cost and a high level of inventory with free cash tied up in working capital. This is definitely a critical concern for any organization, trying to make a trade-off between the strategic factors and the internal operational factors for effective warehousing. There are a few models like gravity location models, network optimization models, computerized simulation models, multiple objective models, etc., for effective warehousing network selection [4, 11, 22]. However, none of these models consider all the subjective and objective issues that affect the warehousing network design and also do not evaluate all the operational and strategic influencing factors in a consolidated manner.

The purpose of this paper is to develop a framework for spare part warehousing decision-making considering both subjective and objective factors for effective plant operations.

LITERATURE REVIEW

In any manufacturing organization, spare parts inventories block a significant amount of cash for which companies emphasizing on maximization of free cash flow focus a great deal on lean and effective spares management. Organizations are unable to achieve effective spares management without considering warehousing structure. A number of researchers and practitioners have studied warehousing decision making from different perspectives like warehouse location, inventory level, capital and operating cost and supply chain responsiveness [23, 24, 30, 31, 32].

S. Chopra and P. Meindl suggest a framework for network design decisions that requires companies to start from looking into the supply chain strategy influenced by global competition, competitive strategy, and companies' internal constraints like capital, existing network etc. [11]. The second phase being the regional facility configuration affected by regional demand, political factors, production technologies, tariffs and tax incentives is followed by the third phase of selection of desirable sites based on response time and available infrastructure.

The final phase is the location choices influenced by factor costs and logistics cost. However the framework does not consider the priorities that the companies should set for each of the influencing factors for the decision-making and the ways of consolidating all of them to make the most optimized warehousing decision.

The models suggested by most of the researchers focus mainly on warehouse location as the most essential criterion while making the warehousing network decision [4, 9, 11]. E. Melachrinoudis and H. Min, identify that the problem of locating warehousing facilities is concerned with the determination of the optimal number, size, and geographic configuration of those facilities in such a way as to minimize the total cost associated with supply chain operations, while satisfying customer demand requirements [21].

D. Ambrosino and M.G. Schutella in their research on complex distribution network design problems, identifies only facility location, transportation and inventory decisions and refers to these problems as the integrated distribution network design problems [1].

They developed some complex mathematical models, where the goal of the analysis was to determine the best distribution system in order to minimize facility, warehousing, transportation and inventory costs, and to grant a certain service level.

This trade-off between cost and service level is similar to the Chopra and Meindl's approach toward supply chain management, which strikes a balance between efficiency and responsiveness in line with Ambrosino's cost and service level. But the approach does not consider the network design from a macro perspective involving the social and economic factors, the warehousing capabilities of the internal organization, the complexity of the process or the organizational structure and the overall company's strategy.

The model of Ambrosino identifies the number of warehouses and their preferred location based on the balance between cost and service level but does not enable firms to make a very basic decision on whether to internalize warehouse management or to outsource to a third party. It is important for organizations to decide on several warehousing alternatives like centralized, decentralized, combination of the two or outsourcing to third party vendors.

Researchers used the gravity model for location decision-making with the consideration of distance from demand and supply points and transportation cost. The network optimization models are used with the consideration of fixed costs, variable costs, capacity and customer demand in order to select an efficient warehouse network [11].

B. Bowersox and co-authors, have suggested other cost based models like total cost network, which emphasize on the trade off between total inventory cost and total transportation cost to select the warehouse network that decides on the number of warehouses and their locations [9].

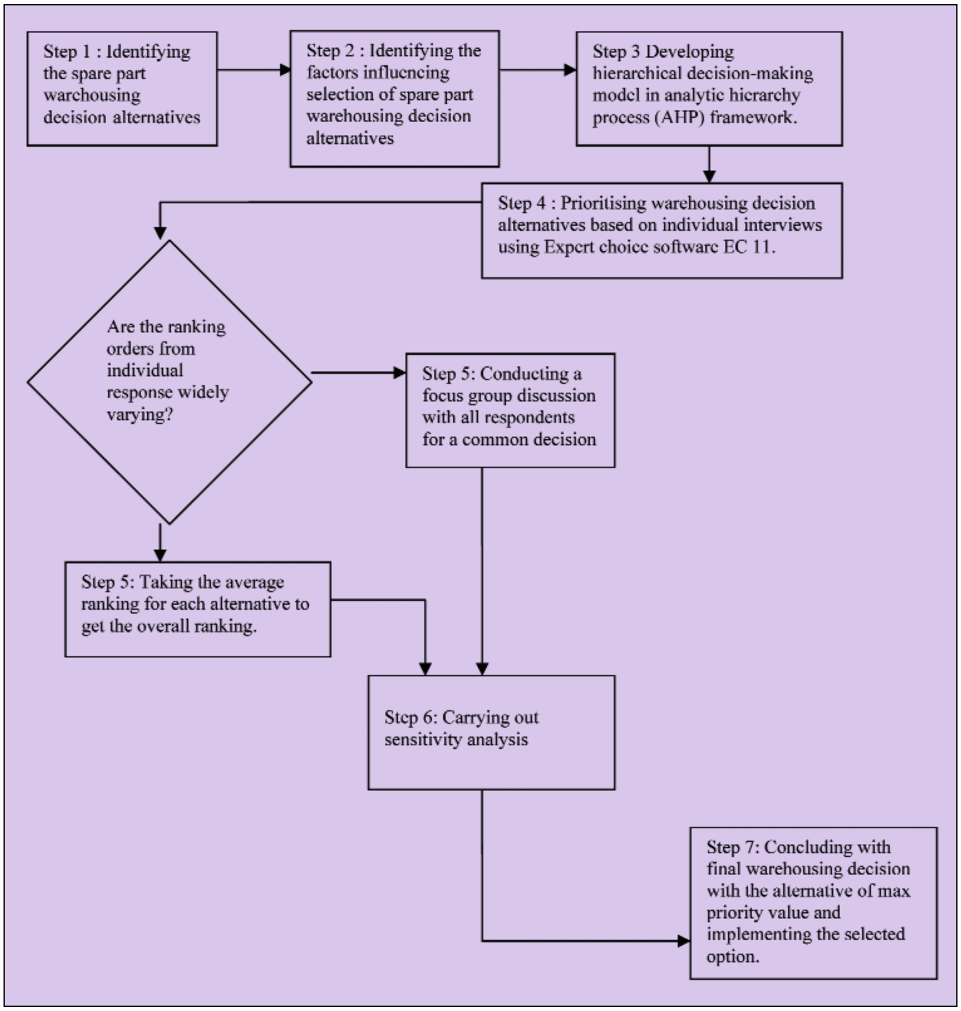

Figure 1 — Spare Part Warehousing Decision Making Framework

However, the only focus on cost based warehouse structure is not helpful for the companies whose strategy might be to be at the higher end of the supply chain responsive structure. Having a single warehouse at some central location might be a sensible cost minimization approach, but may adversely affect the service level.

The conventional models do not consider the strategic and operational factors apart from cost in a single framework to enable managers to simulate them in order to make the decision on warehousing structure. The difficulties researchers might have faced in bringing all these factors under one structure are that some factors are qualitative and some are quantitative, making the simulation complex.

The computerized simulation models, like deterministic simulation or Monte Carlo simulation, are essentially cost calculators, thus focusing more on objective factors rather than subjective factors. Heuristic models achieve a broad problem definition, but do not guarantee optimum problem solutions [4].

These are common sense rules that are used in planning where they may appear as principles or concepts like the most likely sites for input warehouses are those that are in or around the manufacturing facilities; the next warehouse to add to the system is the one that shows the greatest cost savings and so on. These rules are loaded in the computer program for the decision making, but the logic of the program is beyond the knowledge of the managers concerned with warehousing decisions and also these rules are more subjective and intuitive without any concrete objective base.

The latest model that is emerging from the field of artificial intelligence with the advancement of technology is the expert system model. However, not enough application of this model has been reported so far in the field of logistics. The advantage of this model is that it can deal with the quantitative and qualitative information, unlike above mentioned conventional models that deal with either quantitative or qualitative information separately. But the problem with this model is identifying experts, specifying the knowledge base and acquiring their relevant knowledge. But as this system is not existent for the warehousing decision, it cannot be presently considered for use by managers for optimized warehousing.

C. Das proposed a dynamic programming approach to allocate inventory over a number of locations and compared the total cost of centralized versus decentralized inventories [12]. E. Melachrinoudis and others developed a multiple objective model for the consolidation of a warehouse network considering minimization of total distribution costs, maximization of customer services and maximization of intangible benefits associated with the new distribution network [22].

The literature that has been reviewed above clearly indicates that no research has been carried out specifically in the field of warehousing decision making involving the company decision makers in group decision making by considering all the relevant subjective and objective factors like financial, location, inventory, responsiveness, social, environmental, company strategy, supply chain strategy etc.

In the available literature, emphasis has been given mainly on location, inventory level and customer service level. This research project will enable managers to take the most appropriate decision in choosing the most effective warehousing by consolidating all the relevant factors and putting them into an appropriate decision making framework.

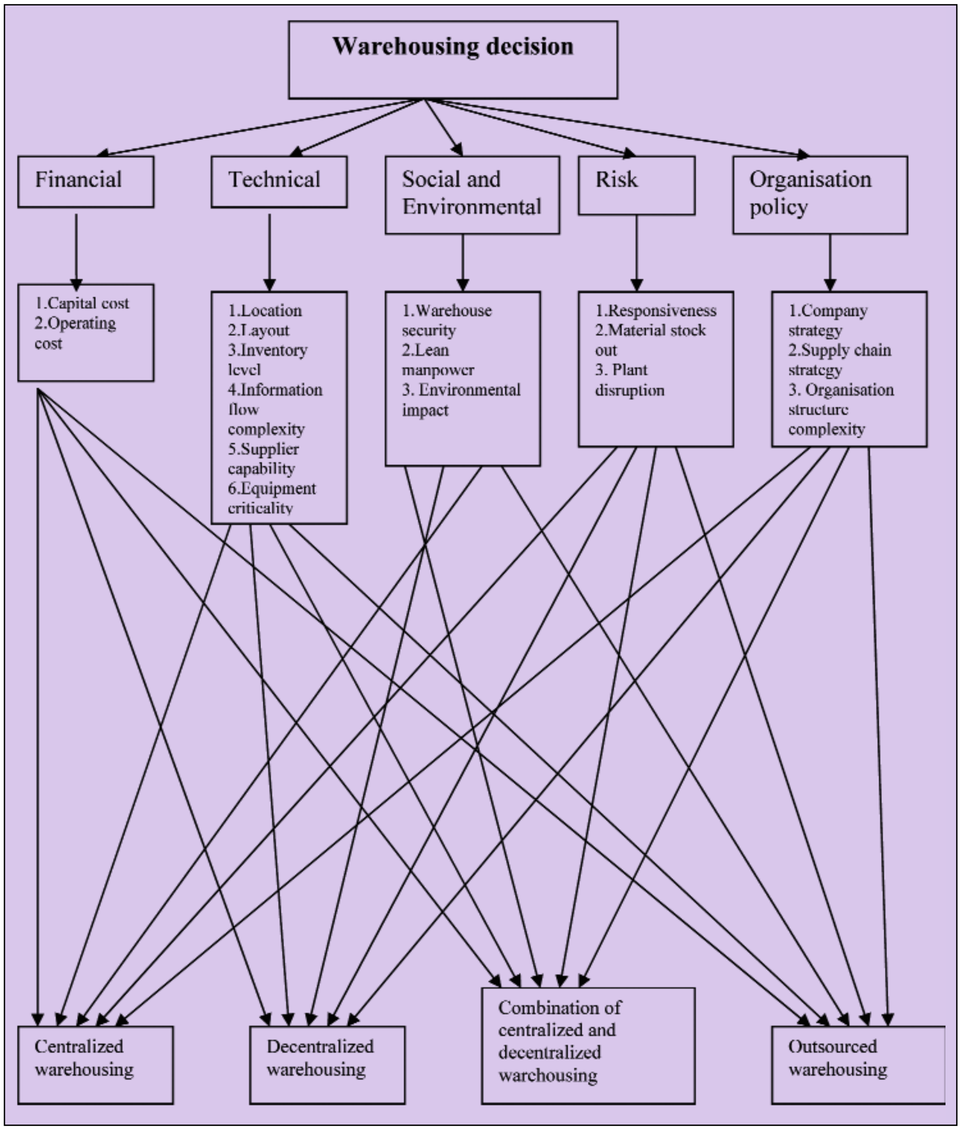

Figure 2 — AHP Based Warehousing Decision Making Model

METHODOLOGY

This study adopted a case study approach. First, a conceptual model was developed using the analytic hierarchy process (AHP) and then the model was validated through a case application in a cement manufacturing organization in the UK. Three plant visits and several interviews were undertaken with the concerned key professionals of the organization.

During the plant visits, discussions with the procurement and warehouse key personnel of each plant enabled the researcher to understand their procurement process and the role of warehousing in the organization. It also helped to understand the warehousing status, its operational and management difficulties so that the factors influencing the warehousing decisions could be identified better.

The warehouse security conditions, the vehicle status, warehouse space, conditions, warehouse management and layout were examined and the working process of warehouse staff and that of the procurement personnel and communication process were understood in detail.

The primary and secondary factors that influence warehousing decision-making were identified and the rationales were developed, based on the current warehousing structure, on the observations made and the discussions had in the various plants and on the consultation with the head of procurement. After the identification of the influencing factors, sub factors and the warehousing alternatives, a decision-making framework was developed using the analytic hierarchy process (AHP).

The Analytic Hierarchy Process (AHP) developed by T.L. Saaty provides a flexible and easily understood way of analyzing complicated problems [26]. It is a multiple criteria decision making technique that allows subjective as well as objective factors to be considered in a decision making process. AHP allows the active participation of stakeholders and gives managers a rational basis on which to make decisions [28].

AHP is based on the following three principles: decomposition, comparative judgement, and synthesis of priorities. AHP is a theory of measurement for dealing with quantifiable and intangible criteria that has been applied to numerous areas, such as decision theory and conflict resolution [33].

Warehousing decision-making is usually a team effort, and AHP is one available method for forming a systematic framework for group interaction and group decision-making [17].

R.F. Dyer and E.H. Forman describe the advantages of AHP in a group setting as follows:

- Both tangibles and intangibles, individual values and shared values can be included in an AHP-based group decision process.
- The discussion in a group can be focused on objectives rather than alternatives.
- The discussion can be structured so that every factor relevant to the discussion is considered in turn. And,
- In a structured analysis, the discussion continues until all relevant information from each individual member in a group has been considered and a consensus choice of the decision alternative is achieved [13].

Further detailed discussion for conducting AHP-based group decision making sessions are given by T.L. Saaty, B.L. Golden, and others; these include: suggestions for assembling the group; constructing the hierarchy; getting the group to minimize inequalities of power, concealed or distorted preferences; and how to implement any results [16, 17, 27]. Problems using AHP in group decision making are discussed further by G. Islie and others [20].

The framework of warehousing decision-making is depicted in figure 1. The framework has been developed with the involvement of the key personnel of the organization under study and using authors' knowledge on the subject along with strong literature support. The framework has seven steps as shown in figure 1.

Step 1 Identifying the spare part warehousing decision alternatives.

Step 2 Identifying the factors influencing selection of spare part warehousing decision alternatives.

Step 3 Developing the hierarchical model in analytic hierarchy process (AHP) framework.

Step 4: Prioritizing warehousing decision alternatives based on individual interviews using Expert choice software EC 11.

Step 5: Conducting a focus group discussion with all respondents for a common decision / Taking the average ranking for each alternative to get the overall ranking.

Step 6: Carrying out sensitivity analysis.

Primary factor	Secondary factor	Definition of the factor	Rationale for consideration
I) Financial	i) Capital cost	The initial investment to be made in terms of new equipments, buildings, facility set up cost(computers, printers, water, phone, gas, electricity etc).	Usually, building up new warehouses is associated with lot of capital investments which are different for different warehousing options. In certain cases like outsourcing to a third party there is virtually no capital investment, whereas for in house models, certain investments are required which might be ranked for each warehousing model based on the level of investment.
	ii)Operating Cost	The ongoing expenditure in terms of internal transportation, stationeries, warehouse maintenance (cleaning, painting etc), employment cost, utilities (like gas electricity, water etc).	The operating cost differs in different warehousing alternatives as it might be expected that the warehouse maintenance and other cost elements would be higher for decentralised warehouses, whereas the transportation cost for transporting spares from the warehouses to the plants would be higher for centralised warehouses. Thus the different alternatives might be ranked based on the level of operation cost.
II) Technical	i) Location	This is the physical distance of the warehouse from the plant	The location factor is different for different warehouse locations and based on the location, the responsiveness or the lead time for the spare to reach the plant is determined. It is obvious that the warehouse distance from the plant would be greater for centralised warehousing than the decentralised model. Thus the different alternatives might be ranked based on the location.
	ii) Layout	This refers to the internal layout of the warehouse so that the items are arranged based on size, frequency of use, ease of handling, air conditioning requirement etc.	Generally the 3rd party has the expertise in designing appropriate layout. Often it is observed that warehouses that are adjacent to the plants are more disorganised as the plant operations have easy access to the warehouses that disturb the arrangement of spares in the warehouse, resulting in a haphazard layout. Thus the different warehousing alternatives might be ranked based on the factor of layout.

Table 1 — Factor Definitions

Step 7: Concluding with final warehousing decision with the alternative of max priority value and implementation of the selected option.

APPLICATION

The developed framework is then applied to a UK-based multinational cement manufacturing organization in order demonstrate its effectiveness. The organization under study is a leading global producer of cement, ready-mix concrete, aggregates and other building materials.

The organization operates three cement plants across the UK, producing a range of products like bulk cement, bulk PFA (pulverized fuel ash), bulk GGBS (ground granulated blast-furnace slag) and packed cement. Presently, each cement plant has its own warehouse within the plant premises that mainly stock the operational and maintenance spare parts. The raw materials like sand, gypsum, clay and chalk are brought from the suppliers on a regular basis by the company owned vehicles to cater to the continuous requirement of the plants. Each cement plant has a main store and several satellite stores within individual plant premises.

Step 1: Identifying the spare part warehousing decision alternatives

The key personnel of plant management of the organization identified four warehousing decision alternatives in a focus group discussion. They were centralized warehousing, decentralized warehousing, a combination of centralized and decentralized warehousing and outsourcing.

Centralized warehousing could be located in a suitable location by optimizing logistics and facility requirements. All the inventory and consignment stock could be stored in this warehouse. All the present satellite warehouses and main stores at individual plant locations could be used for some other plant specific purposes. One warehouse manager could manage the central warehouse and two warehouse operatives could be located at this warehouse.

The organization under study has a decentralized warehousing structure where each of the three plants is having its own warehouses. Apart from the main warehouse in each plant, there are several satellite warehouses, where the spares are stored in a disorganized manner. Currently, the organization operates 18 warehouses for three plants. This not only increases inventory of the plants considerably, but also enhances operating cost of the plant as a whole. However, the organization could improve the warehousing operations by properly

	iii)Inventory level	This is the total value of all types of spares inventories.	The redundant stock might be avoided if consolidated in a central location. Again, if the spares are owned by the third party then the company actually does not hold any inventory and spends only on the replaced parts on a monthly basis without any working capital tied up in inventories.
	iv)Information flow complexity	This is the route of information flow for various activities like order booking, manual purchase, work order request, vendor communication etc.	The complexity might be minimal if plants are adjacent to warehouses as information might be disseminated fast and in a simple way without always taking a formal, lengthy route However, sometimes information flow becomes more complex when the information sharing and communication involves a third party vendor.
	v) Supplier capability	This refers to the number of customers the supplier has and also the network it has with the third party logistics provider so that the latter can store the supplier's spares in its warehouse for supply to the manufacturing companies.	High supplier capability in terms of bigger client base is required when outsourced to a third party as the latter won't take the spare part dealership of the supplier and won't take the interest of storing the supplier's spares. But often third parties don't take the dealership of the spares that are specific to a particular industry sector like refineries, building materials, etc and tend to store general spares that can be used in any industry sector. But, the company with a better and wider network with the good, reputed spare part supplier specific to its industry makes a better deal with those suppliers than the generic third party vendors.
	vi) Equipment criticality	This refers to the criticality of the instruments/equipments installed in the plant in terms of acceptable downtime of the equipment, alternative by-pass process line, redundant equipment in parallel process line etc.	The warehouses that are close to the plant have the option of understanding the criticality of installed equipments and communicate internally to decide on the spare procurement and the stock level. But, this happens if the warehouse staffs take part in the inter–departmental communication meeting. But, often the third party takes the initiative to understand the technical process and jointly takes the decision on spares requirements with the client, as the former gets the incentive of building up a close relationship with the company and reduces its own inventory level to certain extent.

Table 1 — Factor Definitions (Continued)

designing the decentralized warehousing operations through network and logistics optimization.

A combination of centralized and decentralized warehousing could provide the organization an optimized solution to their warehousing option selection. They could have a centralized warehouse and three decentralized warehouses in each plant. All the slow moving, common spares could be stored in the central location. The decentralized warehouses could stock the fast moving consumables and the spares that are unique to the specific plant. The central warehouse could be managed by one warehouse manager and two operatives and each decentralized plant warehouse could be operated by a warehouse manager and two operatives.

III) Social & Environmental	**i)Warehouse security**	This refers to the unauthorised access to the warehouse.	Usually for an outsourcing option, company's own staff won't have any physical access to the warehouse whereas in a decentralised option, the plant team will have regular access to the warehouse especially in silent hours. Thus the different alternatives might be ranked based on the security.
	ii) Lean manpower	This refers to the required no. of staff.	For outsourcing, it may be assumed that the staff level would be at minimum as all the warehousing job would be carried out by third party. In the case of in-house warehousing, there will be different levels of staff requirement to operate the warehouses. Thus the different alternatives might be ranked based on the manpower requirement.
	iii) Environmental impact	This refers to the air, water pollution, road traffic caused and the change in topography.	The impact is at maximum when there is more vehicle movement from warehouses to the plants. Also the topography would be impacted due to new construction of the warehouse. Again the road condition is adversely affected due to frequent movement of heavy vehicles. All these contribute to different environmental impact for different warehousing options.
IV) Risk	**i)Responsiveness**	This is the time required to send the material from the warehouse to the plant after the requirement is notified by the plant.	Depending on the closeness of the warehouse to the plant, the responsiveness varies for different warehousing models.
	ii) Stock out	This refers to the chance of non-availability of the spares when required by the plant.	When the spares are owned and managed by a third party against a contract fee; risk of stock out may be at minimum because of the penalty clause in the contract. But for decentralised option, often each plant warehouse might try to reduce its inventory level, thus increasing the risk of stock-out. However the risk of stock out may be different for different warehousing options.
	iii) Plant disruption	This refers to the disruption to the plant operation or the increase in downtime due to want of spares.	Depending on the closeness of the warehouse to the plant, the disruption to plant varies for different warehousing models as different structures have different material delivery lead time.

Table 1 — Factor Definitions (Continued)

The last option identified by the key personnel of the organization was outsourced warehousing. This option could reduce its stock holding, reduce staff and use its existing warehouse buildings for their plant operations. The vendors could manage and maintain the stock of spares in their warehouses by maintaining close contacts with originally manufacturing enterprises (OME). They have worked on this option and received a preliminary proposal from some of the experienced distributors of industrial MRO products, which include bearings, seals, mechanical power transmission, motors, gearboxes, fluid power components, industrial automation, tools, workplace equipment etc. The vendor could deliver the spares based on requirements as per the agreed contractual delivery time.

Each option has its own pros and cons for adopting. They require to be thoroughly analyzed before selecting the best suited one. Moreover, a consensus decision of the key personnel is key to the success in this type of decision-making.

Cemex, a cement manufacturing organization has plant specific decentralized warehouses adjacent to each plant [10]. It has been reviewed by Cemex personnel that the warehouse operating expenditure and spare part inventory are quite high. However spares delivery responsiveness is very satisfactory.

On the other hand, centralized warehousing would decrease the operating expenditure, but reduce the responsiveness. However, the combined model would consider the responsiveness factor and strike a balance by storing urgent consumables in plant stores and non-critical spares in centralized store. But this model would further increase the warehouse operating cost for running both centralized and plant stores. Lastly, the option of outsourcing will reduce the operating cost for Cemex, but the dependence on the vendor for parts delivery increases the risk of undesirable plant shutdown for want of spares.

V) Organisation policy	i) Company strategy	The overall company strategy in terms of profitability or free cash flow maximisation.	The warehousing structure should be aligned with the overall company strategy. The redundant spares in different warehouses increase the working capital tied up with inventory and reduce the free cash flow. Thus different warehousing models may be ranked based on the strategy for maximising free cash flow
	ii) Supply chain strategy	This refers to the value of inventory carried per tonnage of product made.	The warehousing structure should be aligned with the supply chain strategy, which is further aligned with the company strategy. The different warehousing models may be ranked based on the strategy for reducing the value of inventory carried per tonnage of material produced.
	iii) Organisation structure complexity	This refers to the number of organisational levels (hierarchies) in the warehousing division and the reporting structure.	In case of outsourcing there is just a single contact point to deal with the third party, hence the complexity would be minimum. Whereas for in-house warehousing, the warehouse staff would have a reporting structure in a particular hierarchical order, thus making the structure more complex which would be again different for different options like centralised, decentralised or the combined warehousing model and thus may be ranked accordingly based on the organisational structure complexity.

Table 1 — Factor Definitions (Continued)

Step 2: Identifying the factors influencing selection of spare part warehousing decision alternatives

The factors for analyzing the best warehousing option for the organization under study have been identified based on the previous literature of warehousing and on the discussions carried out with company professionals in the related fields of warehousing, procurement, operations and maintenance during the authors' visits at three different plant locations.

Table 1—explains the identified factors and sub factors that influence the appropriate warehousing decision making.

Step 3: Developing the hierarchical model in analytic hierarchy process (AHP) framework.

Using the information from step 1 and 2, a hierarchical decision support system (DSS) in the AHP framework was developed. Figure 2 demonstrates the proposed DSS. The first level is the goal, which is to select the best warehousing option. The second and third levels are the factors and sub factors respectively, which are required to be considered in order to achieve the goal. The last level is the decision alternatives, which are various warehousing alternatives as derived by the key personnel of the organization under study.

Step 4 : Prioritizing warehousing decision alternatives based on individual interviews using Expert choice software EC 11 [14].

The proposed DSS was presented to each key personnel (plant director, head of procurement, engineering manager, operations manager, procurement manager, operations coordinator, quality manager and mechanical engineer of the plants) separately with detailed information on AHP and its applications for decision-making along with a demonstration of the Expert Choice software.

They first derived importance of the factors by pair wise comparison using the Saaty's scale (table 2). Table 3 shows the factor level comparison matrix, normalized matrix and weights as a sample response and analysis. Subsequently, they derived the importance of the sub-factors using pair wise comparison. Lastly, the priorities of each of the warehousing options was derived with respect to each sub-factor by pair wise comparison using Saaty's scale (table 2). All the derivations were carried out using Expert Choice software. Finally, synthesizing the result across the hierarchy derived the overall ranking of the alternate options using Expert Choice. Table 4 shows a sample calculation of overall ranking of the warehousing decision alternatives. In every level the consistencies of each matrix were checked and found that these were within 10 percent, which were acceptable.

This step resulted individual priority vectors from each key personnel. The results are shown in table 5.

The results revealed that out of a total of eight interviews, the option of outsourcing has received rank 1 six times, decentralized has received rank 1 once and centralized warehousing has received rank 1 once.

This gives the overall ranking of the four alternatives as the following.

Rank 1 - outsourced warehousing;
Rank 2 - centralized warehousing;
Rank 3 - decentralized warehousing; and
Rank 4 - combined warehousing.

Step 6: Taking the average ranking for each alternative to get the overall ranking.

As six out of eight interviews resulted in outsourcing as the best suitable alternative, Step 5 of focus group discussion has been eliminated and all the priority vectors for each alternative have been averaged to obtain the final ranking of the alternatives.

This gave the following averaged priority scores as shown in the table 6. This is obtained by taking the average of each column of table 5 (Ranking order of eight interviews).

The analysis clearly revealed that the outsourcing option outranked other alternatives.

Step 6: Carrying out sensitivity analysis with change in importance of critical factors.

The sensitivity analysis was then carried out to reveal the impact of the changes of importance of the most critical sub factor, which is capital cost with the highest priority score on the ranking of warehousing options.

Figure 3 depicts the sensitivity analysis of the decision options.

From the above graph, it is observed that if the importance level of capital cost goes above 0.6 or so, the ranking pattern will change and centralized warehousing takes the second position whereas decentralized takes the third position. However the option of outsourcing is still the preferred option and its position remains the same irrespective of the priority score of the capital cost. This might be because more capital investment is associated with other warehousing options except outsourcing in terms of building, land, management set up, ICT set up etc . Even if capital cost changes its score, the outsourcing always gets the maximum preference with least capital investment.

Step 7: Concluding with final warehousing decision with the alternative of max priority value and implementing the selected option.

The overall priority scores of the alternatives and the sensitivity analysis indicate that outsourced warehousing is the best option for the organization under study with average score of 0.41. The ranking pattern also remains unaltered in most of the cases in the sensitivity analysis as shown in Step 6. Management could proceed with the outsourcing option and shift from their existing decentralized warehousing to outsourced warehousing.

DISCUSSION

This research proposes a spare part warehousing decision-making framework based on the analytic hierarchy process (AHP), a multiple attribute decision-making technique. This model can be applied to any manufacturing organization with plants at different locations.

The warehousing alternatives and the subjective and objective factors influencing the selection of the most appropriate warehousing option were identified and analyzed with the involvement of the key professionals. The analysis revealed that the best option was outsourced warehousing for the organization under study.

Outsourcing has widely been considered as one of the major means of improving both the competitiveness and effectiveness of companies. Focusing on core competencies and outsourcing the rest to specialized suppliers has been the trend for decades, especially in manufacturing industries. This research enabled the organization under study to make final decision on the appropriate warehousing option, which was the outsourced warehousing. It helped the organization to improve cash flow by reducing the regular high operating cost of the decentralized warehousing system and reducing inventory level considerably.

This research derived a comprehensive decision-making framework for spare part warehousing option selection with the involvement of both the top management and operating people. This ensures the consideration of all the strategic and operating factors for making decisions, management commitment and practice of suggested option upon implementation

The research has been conducted with the help of a case study with a single organization. Though the AHP based decision support system (DSS) has been

Verbal Judgement of Preference	Numerical Rating
Extremely Preferred	9
Very strong to extremely	8
Very strongly preferred	7
Strongly to very strongly	6
Strongly preferred	5
Moderately to strongly	4
Moderately preferred	3
Equally to moderately	2
Equally preferred	1

Table 2 — Nine-Point Pairwise Comparison Scale

Factor level comparison matrix

primary criteria	financial	technical	social	risk	Org policy
financial	1	4	5	2	3
technical	0.25	1	2	0.333333333	0.5
social	0.2	0.5	1	0.25	0.333333333
risk	0.5	3	4	1	0.5
Org policy	0.333333	2	3	2	1
SUM	2.283333	10.5	15	5.583333333	5.333333333

Normalised matrix

primary criteria	financial	technical	social	risk	Org policy	Mean of the rows (priority vector for each primary criterion)
financial	0.437956	0.380952381	0.333333333	0.358208955	0.5625	0.414590175
technical	0.109489	0.095238095	0.133333333	0.059701493	0.09375	0.098302394
social	0.087591	0.047619048	0.066666667	0.044776119	0.0625	0.061830615
risk	0.218978	0.285714286	0.266666667	0.179104478	0.09375	0.208842706
Org policy	0.145985	0.19047619	0.2	0.358208955	0.1875	0.216434109

Consistency ratio calculation

New vector	New vector/priority vector	C.I. for primary factors	C.R. (CI/RI) for primary factors
2.18394057	5.26770942	**0.04885944**	**0.0436245**
0.50344246	5.12136516		
0.31825523	5.14721109		
1.06658449	5.1071187		
1.15441288	5.33378442		
Mean=	5.19543776		

Table 3 — Priority Vector Calculation Matrix for Primary Factors

developed keeping any manufacturing organization in mind and all the probable influencing factors have been critically thought of, the generalization of this DSS for all types of manufacturing organizations may be made after validating the model in other manufacturing companies in other industry sectors apart from cement manufacturing.

Although in this study every effort has been put in to quantify the warehousing decision alternatives by modeling all factors of warehousing in accordance with perceptions of experienced process owners, subjectivity could not be eliminated completely. Additionally, AHP as a method of decision-making has its own limitation as pointed out by many authors [5, 6, 15].

Although this research reveals outsourcing as the best warehousing option for spare parts management for the organization under study, there are various ways of outsourcing, which this study didn't discuss. Therefore, a subsequent study can be taken up to carry out the detailed feasibility analysis of this option along with alternate analysis. There is further scope of identifying the potential risk of outsourcing with the consideration of social, political, financial, technical and strategic risk factors, analyzing their severity and resolving with appropriate solutions. Further research can also be carried out in the area of supply chain network design using information and communication technology (ICT) for an effective two-way communication between the outsourced vendor and the client organization.

Unpredicted equipment downtime has long been recognized as a major source of uncertainty in manufacturing organizations and is very costly in terms of lost production. Lack of spare parts required for preventive and/or breakdown maintenance is an important cause of excessively long downtimes. However, inventory is expensive and can quickly become obsolete as equipment models change. Therefore, management of any organization must balance the conflicting goals of minimizing inventory investment and maintaining high equipment availability. This aspect makes appropriate warehousing network design a critical issue for any manufacturing organization.

Several researches have been carried out on inventory management [3, 18, 19, 25]. Also there are researches on spare part warehousing, identifying warehouse location, inventory level and required delivery time as the main factors affecting warehousing decision making [1, 11, 21]. However, so far, no research has been carried out in building a holistic group decision support system for spare part warehousing option selection for the process industry considering all the strategic and operational factors that affect the decision making. This research addresses this gap by developing a spare part warehousing DSS using the analytic hierarchy process. This framework considers all the strategic and operational factors for spare parts warehousing option selection and analyzes with the involvement of the key personnel of the organization.

The proposed model has been applied to a UK-based multinational cement manufacturing organization in order to select their spare parts warehousing option.

Primary	Primary priority vector	Sub	Sub priority vector	A(Local priority)	A(Global priority)	B(Local priority)	B(Global priority)	C(Local priority)	CGlobal priority)	D(Local priority)	D(Global riority)
Financial	0.4146	capital Cost	0.8333	0.2473	0.0854	0.0657	0.0227	0.0709	0.0245	0.6161	0.2129
		operating cost	0.1667	0.05779	0.004	0.256	0.0177	0.0991	0.0068	0.5871	0.0406
Technical	0.0983	Location	0.1564	0.05357	0.0008	0.5258	0.0081	0.254	0.0039	0.1667	0.0026
		Inventory level	0.0777	0.2298	0.0018	0.0444	0.0003	0.086	0.0007	0.6398	0.0049
		Information flow	0.241	0.54139	0.0128	0.2634	0.0062	0.0579	0.0014	0.1373	0.0033
		Warehouse layout	0.0542	0.29392	0.0016	0.1334	0.0007	0.0937	0.0005	0.479	0.0026
		Supplier capability	0.1216	0.5791	0.0069	0.067	0.0008	0.1213	0.0014	0.2326	0.0028
		Equipment criticality	0.3491	0.06246	0.0021	0.2946	0.0101	0.1038	0.0036	0.5392	0.0185
Social	0.0618	Warehouse security	0.6333	0.19746	0.0077	0.0746	0.0029	0.1157	0.0045	0.6122	0.024
		Lay offs	0.2605	0.24085	0.0039	0.0557	0.0009	0.0808	0.0013	0.6226	0.01
		Environmental impact	0.1062	0.05292	0.0003	0.5757	0.0038	0.239	0.0016	0.1323	0.0009
Risk	0.2088	Responsiveness	0.2114	0.06753	0.003	0.5431	0.024	0.2219	0.0098	0.1675	0.0074
		Stock out	0.1335	0.55186	0.0154	0.0513	0.0014	0.1312	0.0037	0.2656	0.0074
		Plant disruption	0.6551	0.09597	0.0131	0.4658	0.0637	0.1611	0.022	0.2771	0.0379
Org policy	0.2164	Company strategy	0.539	0.19422	0.0227	0.0639	0.0075	0.1082	0.0126	0.6337	0.0739
		Supply chain strategy	0.2973	0.1939	0.0125	0.0576	0.0037	0.091	0.0059	0.6576	0.0423
		Organisation structure	0.1638	0.2333	0.0083	0.0847	0.003	0.1397	0.005	0.5423	0.0192
Sum total					0.2023		0.1776		0.1091		0.511
					Centralised inhouse		Decentralised inhouse		Combined inhouse		Outsourcing

Table 4— Overall Ranking of the Warehousing Alternatives

The study revealed that outsourced warehousing should be the best option compared to the other available options (centralized and centralized cum decentralized), although the organization currently operates a decentralized warehousing option.

The AHP-based spare parts warehousing decision making framework is effective for selecting the most appropriate warehousing option for the manufacturing organizations. This study reveals that the same techniques could also be applied in other manufacturing organizations for decision making of the most appropriate spare parts warehousing option. ◆

Key personnel	Centralised	Decentralised	Combined	Outsourcing
Head of Procurement	0.250699	0.265684	0.211794	0.271823
Procurement Manager	0.18849	0.17076	0.085921	0.55482
Operations Coordinator	0.20232	0.17756	0.109095	0.511021
Plant Director	0.14645	0.32002	0.12584	0.407682
Quality Manager	0.151618	0.348864	0.1731	0.326415
Engineering manager	0.36227	0.22505	0.19267	0.22002
Mechanical engineer	0.11252	0.25988	0.13966	0.487939
Operations Manager	0.22632	0.15072	0.111765	0.51119

Table 5— Ranking of Each Decision Alternative as Per the Key Personnel

	Centralised	Decentralised	Combined	Outsourcing
Average ranking	**0.205085875**	**0.23981725**	**0.143730625**	**0.41136375**

Table 6— Average Ranking of the Alternative Based on Eight Interviews

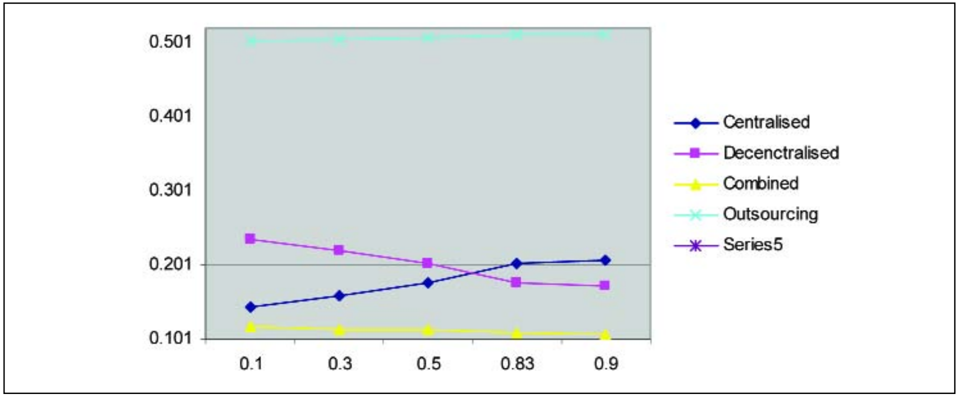

Figure 3— Sensitivity Graph of Warehousing Alternatives with Respect to Capital Cost

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From the cover ...

On the cover of this month's **Cost Engineering** journal are photos of AACE International member Sylvester C. Myers, at the Morgantown/Kingwood Branch of the National Association for the Advancement of Colored People (NAACP) annual Freedom Fund Banquet in April.

Myers was keynote speaker for the banquet. In the photos, beginning with the top photo and moving clockwise, Myers delivers his keynote address. Looking on are Otis G. Cox, vice President of the Morgantown/Kingwood Branch; his wife, Wanda Cox, secretary/treasurer; Janice Myers, wife of the speaker; Eddie Belcher, regional representative for West Virginia Governor Joe Manchin; and Debbie L. Robinson, President of the Morgantown/Kingwood Branch. Not shown is Lt. Col. Kenneth L. Hale, President of the West Virginia State NAACP.

In the next photo Janice and Sylvester Myers greet AACE International Staff Director Education and Administration Charla Miller and her husband, Eugene Miller. In the next photo Myers talks with the Rev. Theodore T. Buckner, President of the Fairmont Branch. and in the last photo, Mr. and Mrs. Myers greet Debbie Robinson, President of the Morgantown/Kingwood Branch.

Myers spoke on the history of the NAACP within the US. He was also in town to promote his book, **From Coal Fields to Oil Fields and Beyond, A Life in Pursuit of All I Could Be**. This is his memoir and covers his life up through 1998.

Myers is CEO and President of S.C. Myers & Associates, Inc., of Washington, DC. This is an independent consulting firm that provides construction cost control and project management services all over the globe. Between 1962-67, Mr. Myers was the first African American to integrate the engineering staff of the Kansas City Corps District office. He was the first black cartographic technician employed by the Corps. He served nine years with the Huntington, West Virginia District Corps Office, and 11 years in Saudi Arabia as a cost engineer and "budget watchdog" of a $20 billion military construction program with the US Army Corps of Engineers. He has traveled to 60 countries around the world. ◆