Classification of spare component inventories and recommendations for policies using a combined approach

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Abstract— Spare parts management has become inevitable for a process industry in order to warrant the readiness of spare items for continuance and repair of the plant and equipment at an optimum cost. The widely accepted ABC classification is common to use and simple to comprehend, but it only considers a single metric, such as annual usage value. It is acknowledged that criticality also has a significant role in the categorization of inventories. Here, taking into account the annual consumption value and criticality, VED analysis has been integrated with the current ABC approach for spare parts management in an upstream organization. The facility center considered during this examination has an inventory of 15027 items, some of which are vital to maintain equipment safety and output. This hybrid approach is found beneficial in deciding the most crucial parts which have a direct control over equipment functionality, irrespective of the usage value of the item. The study concluded by recommending a number of inventory management strategies that for each class of items, when put into practice, will both lower holding costs and improve the facility's production efficiency.

Keywords— ABC analysis, Criticality, Pareto principle, Safety stock, Service level, VED analysis

1. Introduction

Since inventory can account for up to half of all invested capital, it is the most expensive asset of an organization. So, it is the responsibility of the material management department to procure, preserve and deliver spare parts in time to assure smooth progress of the project. It is paradoxical to note that while the finance department struggles with rising locked-up capital in spare parts inventory, the production department laments the lack of spare parts availability to meet its demand. Because of this, it is imperative to manage inventories effectively in order to prevent making unneeded investments. The company must use straightforward inventory planning and control strategies to reduce its stockpiles to a manageable level without jeopardizing its sales or manufacturing operations.

The inventory of spare parts must be analyzed based on a variety of factors such as unit price, yearly consumption value, criticality, lead time, frequency of usage etc., in order to manage spare parts effectively and efficiently. Inorder to grasp the method used in this study one should know about the inventories carried out by the oil and natural gas exploration company understudy. The inventories used in the upstream company under study have been broadly classified into two separate groups: “stores” and “spares.” Store items have not been covered during the projectwork as we focused only on spare items. The organization maintains a large number of spare parts in safeguard, ensuring the efficiency of oilfield machinery and assisting the business in reducing facility and equipment downtime. Here, we specifically discuss the handling of spare parts in overhaul projects using an example from an oil and gas exploration company. We began by classifying the spare parts using a quantitative method. Then, in order to further sorted the spare parts, we concentrated on a qualitative technique. Then we merged the two methods to separate the crucial few items from the unimportant many that require strict management.

2. Literature Review

Spare parts inventory management is a must while working with unpredictable demand. Inventory management is essential for maintaining production continuity and preventing downtime losses. Since spare parts are essential for the machinery and equipment deployed to generate tangible commodities or intangible services, material management is constantly on the lookout for them. Guaranteeing that good quality spare parts are available in the right quantities and at the right time is very difficult. This necessitates a thorough classification of spare parts inventory since the business must balance the expense of inventory holding caused by stock piling in the warehouse with the downtime loss brought on by the unavailability of the spare parts.

In various literatures, research scholars suggested different techniques and models to address the inventory problems. One of the most used conventional methods for spare parts inventory classification in manufacturing and service industries is ABC analysis [1,30]

The ABC analysis ignores other considerations such as “criticality” that may be essential for decision-making because it is solely centered on the financial value of the inventory. The company could experience significant production downtime losses due to non-availability of critical spare parts at the time of machine failure. So, it is absolute necessary to consider criticality along with the annual consumption value of spares for inventory classification. It is challenging and complicated to evaluate the criticality of spares using quantitative methods while conducting VED analysis. Different research explains how to assess the criticality of spares using analytical hierarchy (AHP) process [2,3].

To increase operational effectiveness, the pharmaceutical industries heavily rely on the traditional ABC, VED, and FNS systems of inventory management. 393 pharmaceutical products sold by the Ethiopian Pharmaceutical Supply Agency (EPSA)-Jimma hub were categorized using a combined ABC-VED-FNS matrix analysis [28]. For the best possible inventory control of pharmaceuticals, this study [4] also recommends adopting different inventory control rules and methodologies as standard procedure.

At a major oil refinery, Eric Porras and Rommert Dekker [29] compared different re-order point methods for effective spare parts inventory control. Different demand modelling techniques such as Normal model, Empirical model and Willemain model were used to evaluate and compare inventory using real field data.

A novel technique known as combined analysis technique (CAT) is used by the researchers to address the issues with spare parts inventories [5]. In this CAT, various inventory control methods, including ABC analysis, VED analysis, FSN analysis, and SDE analysis, are integrated with various weighting variables to maintain a balance between stock-outs and inventory holding costs.

Safety and health at work are crucial in every industrial environment. Furthermore, the intensity of unfavorable effects or the likelihood of health hazards occurring can be significantly higher, particularly for specific industries dealing with the exploration of oil and natural gases. An integrated ABC-VED matrix was developed to address the inventory management issue by highlighting the impact of health and safety concerns and recommending affordable fixes [6]. Though the ABC technique is widely used to group items into ordered categories, such as A, B and C, the weights of the criteria and categorization preferences can change from industry to industry. The multi-criteria ABC inventory classification problem is addressed by applying UTADIS (Utilities Additives DIS-criminates) based sorting techniques.[7] This study, which is presented in a research paper, attempts to create a multi-criteria classification for defining a stock management policy for each spare part [8]. Price, criticality, and lead time are taken into account as the categorization criteria for spare parts, and a computerized management system has been developed to incorporate these factors.

The serviceability of the service business is also negatively impacted by the lack of spare parts availability. Therefore, inventory classification in the service sector is just as crucial as it is in manufacturing industries. A model was constructed to categories 15,000 spare parts as suitable for the central warehouse by applying traditional ABC and third dimension VED analysis, according to research done by researchers in a central warehouse holding 50,000 products [9].

During the COVID-19 period, startups experienced significant difficulties managing their respective sectors. If SRI DEVI SNACKS, a startup in India, had not adopted the management strategies advised by [10], it might have perished. Selecting a potential supplier of spare parts that can lower ordering costs on the one hand while improving quality on the other can also be done using a combination of the ABC and VED approaches [11].

More than hundred papers on spare parts inventory management that were published between 2010 and 2020 were extensively reviewed.[12] Two kinds of views are used to categories the studies. The traits of products, inventory systems, supply chains and replacement components are included in the first group, whereas the second group focuses on the traits of research procedures and subjects in the analyzed papers. Finally, the reverse logistics, customer durable products, stock network layout and policy, spare parts demand pattern modelling, and big data analytics were the perspectives used to highlight the research gaps in this area.

Understanding the issues engineering organizations face and the strategies they use in their spare parts supply chains is the main goal of the case study research given in this article [13]. One study tries to comprehend how top-performing businesses work on improving their service levels, assuming that both warehouse and inventory management are crucial to attaining this objective.[14] [15,16] proposes a linear programming model that incorporates both quantitative and qualitative criteria for inventory classification. Different weights have been assigned to each item depending on level of criticality of that item. [17] provides an improved model which is a nonlinear programming model that establishes a standard set of numerical weights for all inventoried goods, in contrast to the model developed by [15]. According to a case study [18] done in the manufacturing sector, suppliers have a very high Sigma level. According to the study, appropriate inventory planning implementation would undoubtedly aid in lowering the Sigma level as well as waste, inventory holding costs, and processing costs. This paper [27] extends the model proposed by [15,18] for multiple criteria inventory classification based upon Shannon entropy. A numerical illustration is finally conducted to compare the proposed model with the available Ng-model and HV model.

A multi-item, two-echelon spare parts inventory problem is taken into account in this study [19], and a heuristic solution is offered that minimizes inventory holding and fixed ordering under the restrictions of aggregate and individual response times.

No matter the industry, spare part management is necessary to protect the machinery deployed for production or service. Additive manufacturing (AM) industries cannot escape from this. The review paper by [20] lists the replacement parts needed for AM machinery and asserts that managing spare parts is a multi-criteria decision-making problem that can be resolved using different MCMD techniques. The effect of duplicate item codes on spare part ordering procedures and, consequently, on holding costs is discussed in a few literatures. A problem related spare part inventory was studied by [21] in a big energy company situated at Statoil ASA. The study recommended various inventory control procedures to address the issue of duplicate item codes. The value of spare parts inventories was found to have decreased by about 50% with the application of the model suggested by [22]. The Pareto analysis and CVA (customer value added) analysis were integrated to create the proposed production planning model. [23] believe that the most efficient technique is to group items based on the data contained in their control policy values and their performance-related parameter values, as opposed to grouping items based on similarities in unit cost, demand rate, or lead time (LT). In this context a performance-based inventory classification (PBIC) method is developed using a multi-item, multi-echelon inventory system under continuous review.

Stock keeping units (SKUs) can be grouped into category A, B, or C items using non-traditional methods like artificial intelligence-based methodologies in terms of ANN, BP, and GA [24]. It is also possible to use fuzzy rules [25] to determine ordering policies for items in classes A, B, and C.

After the inventory is classified, the two crucial questions of what to stock and how much to stock immediately follow. [26] uses a pragmatic approach to provide the answers to the questions raised above.

3. The Case Study

Numerous equipment has been installed by the abovesaid upstream company at different potential sites to carry out various production activities such as exploration and production of oils and natural gases. To ensure functioning conditions, spare parts inventory is kept for replacement equipment. The company's MM (materials management) department makes decisions about the purchase of spare parts, which are determined by consumption requirements generated at the installations. Requests from different departments of the organization for materials kept on warehouses are met from the available stock.If there is shortage of a material, an emergency replenishment order is requested with the user department to the MM department. But if this shortage is related to highly critical items, then there is a chance of production break down which incurs a severe downtime loss. As a result, there is a significant trade-off between the inventory carrying cost and service level, two metrics linked to the goals of various business units.

An extensive study was carried out in the company for the fiscal year 2022-23. At present, the company is using an enterprise resource planning (ERP) system, where all information related to spare parts is stored. In total, there are about 15,020 codes of items managed in the system. Our study revealed that only 813 spare items (excluding store items) have been consumed during the fiscal year 2022-23. The data relating to type of spare items, unit price of the item, annual consumption and expenditure incurred on those consumed spare items were collected from the ERP system. Following data collection, appropriate inventory classification methods were employed to group the items into distinct classes, and recommendations for inventory policies were made for each class.

4. Methodology

The said company stocks thousands of spare items in its facility center. Out of those items, many items have been locked up in the warehouse for the last five years, thus increases the inventory carrying cost. On the other hand, the company suffers a very high downtime loss due to the unavailability of spare items at the time of equipment maintenance. Thus, a tradeoff is needed between the inventory holding cost and stock out cost.
Traditional ABC analysis is the most widely used inventory classification technique that divides the entire inventory into three distinct groups based on Pareto principle. Pareto principle also known as 80-20 rule, sates that 80% of the total consumption value account for only 20% of the stock items. This ABC technique categorizes items into three different classes i.e. A, B and C based on the annual usage value.
The characteristic features of these classes are shown in the below table:

Table 1: Characteristics of A, B and C class items

Class	Cost (%)	Volume (%)	Consumption value
A	70-80	5-10	High
B	15	30	Medium
C	5-10	50-60	Low

This technique aids selection of policies for selective control. Our research methodology discusses and explains the data collection and their analysis that starts from ABC analysis followed by VED analysis.

4.1 Data collection and Analysis

Relevant data was collected from the materials management department of the said company. The annual usage of spare parts with respect to volume, unit cost and frequency were collected for the fiscal year 2021-2022. The annual usage value was used in ABC analysis and the item criticality was used in VED analysis. Statistical functions which are available in the Microsoft excel were used for compilation and descriptive analysis of the collected data. The steps involved in our study to categorize combined ABC-VED analysis and the formation of a square matrix are as follows:

Step1: The ABC classification was computed out based on annual usage.
Step2: The VED classification was carried out based on the spare's criticality
Step3: The square matrix was formed by combining ABC and VED analysis

4.2 Quantitative Technique: ABC Analysis

According to this analysis, spare parts were classified on thebasis of annual consumption value. A Pareto analysis (80-20) was undertaken for all the spare items being identified. Where the cumulative cost figure stood at 80% of the total cost, the earlier items in the list were termed as 'A' class items. Similarly, in this ranking system, where the cumulative figure read 90% of the total cost, the items between 80% (exclusive) and 90% were named 'B' class items. The rest of the items were read as 'C' class items.
Various steps followed in the ABC analysis are presented inthe form of a flow diagram given below:

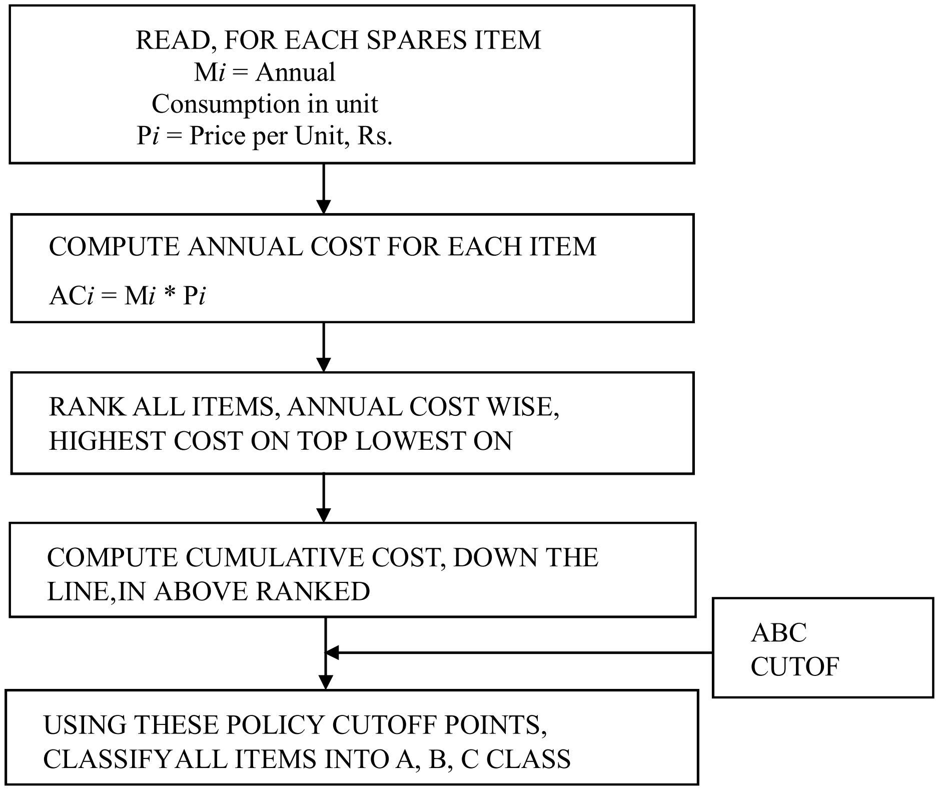

Fig. 1. Flow Diagram for ABC Analysis

4.3 Qualitative Technique: VED Analysis

Qualitative techniques are primarily relied on the experience and opinions of expert members working inside or outside the organization. These methods use human judgement and rating schemes to turn qualitative information into quantitative estimates. The objective here is to bring together in a logical, unbiased and systematic way all information and judgements which relate to the factors being estimated.

Sometimes it has been seen in real practice that machines become paralyzed in the absence of spare items of low monetary value being vital in nature, which is the main drawback of ABC classification. A heavy downtime loss is incurred due to the non-availability of those spare items at the time of need. In order to avoid such type of situations, materials need further classification based on their criticality to increase the oilfield equipment availability and reliability. Hence the spare parts are further categorised using the traditional Delphi technique into three distinct categories: V (Vital), E (Essential), and D (Desirable), considering the expert members' subjective knowledge of the organisation under study.

Table 2. Different levels of Criticality

Level of Criticality	Description
Vital: V	- On account of materials non-availability there will be very high loss due to production downtime. - unavailability of an item makes the whole system inoperative. - Immediate supply of the materials is required. - Risk in the process of ordering and stocking is not tolerated.

Essential: E	- Due to unavailability of items, moderate loss is incurred. - non-availability of an item reduces the efficiency of the system. - Materials should be supplied within a short time period. - A calculated risk in the process of ordering and stocking.
Desirable: D	- Production loss is not very significant due to the non-availability of items. - unavailability of an item will not cause an immediate production stoppage. - Supply of materials after a long period of time. - Risk in the process of ordering and stocking is normal.

Different steps followed in the VED analysis are presented in the form of a flow diagram given below:

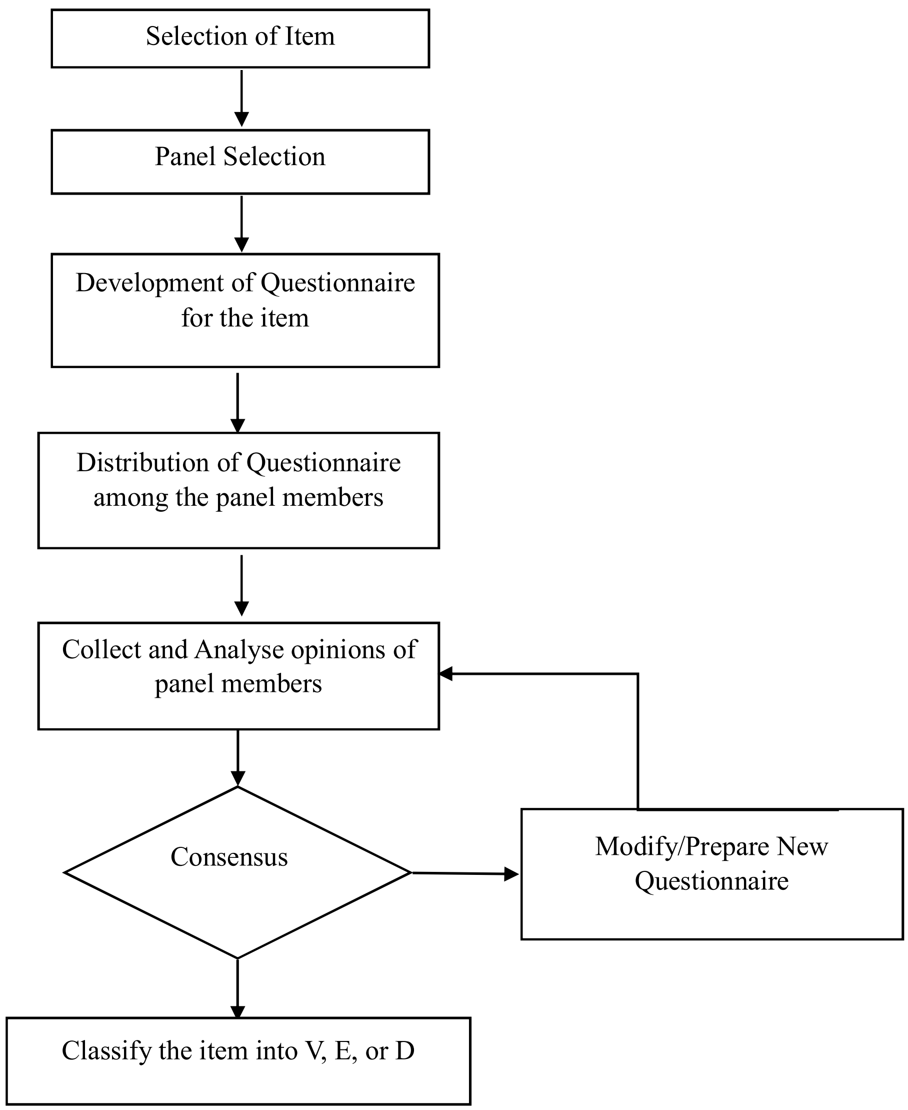

Fig. 2. Flow Diagram for VED Analysis

4.4 Matrix formation - combined ABC and VED

By merging the ABC and VED analyses, a third order square matrix was created for this investigation.

ABC/VED Classification	V	E	D
A	AV	AE	AD
B	BV	BE	BD
C	CV	CE	CD

Three different categories were structured by considering all elements of the matrix, when arranged in a specific way which is given below:

Category I: AV+BV+CV+AE+AD
Category II: BE+CE+BD
Category III: CD

The first alphabet in these subcategories (such as AV, BV, CD, etc.) indicates its position in the ABC analysis, whereas the second alphabet indicates its position in the VED analysis.
Category I is the high priority group, needing greater attention, category II of lower management priority and category III is thelowest priority group, consisting of only CD category of items.

5. Results and Discussion

Table 1 reveals that out of 813 items, 117 items (14.39%) consume 67.98% of annual value classified into class A, 90 items (11.07%) consume 16.33% of annual value classified into class B, and 606 items (74.54%) consume 15.69% of annual value forming class C. The above results unveil that class-A items are few in number but holds a significant amount of total inventory cost. In contrast, class-C items are large in number and account for only 15.69% of the company's material cost. So, it is strongly recommended that the high value items should be controlled by the topmanagement of the company by continuously reviewing quotations from more than one vendor to determine the best market price. To control the inventory of C class items, lower cost methods (such as the two-bin system) is advisable. Class B items can be controlled by following intermediate policies.

Table 1 ABC Classification of Spares

Class of Items	Annual Usage (Rs.)	% of Total Annual Usage	Number of Items	% of Total Items
A	13,393,437.582	67.98	117	14.39
B	3,216,840.304	16.33	90	11.07
C	3,090,725.428	15.69	606	74.54
Total	19,701,003.314	100	813	100

Table 2 indicates that 45 items (5.54%) are vital, 716 items(88.07%) are essential and 52 items (6.39%) are desirable. The company must maintain higher safety stocks if it wants to have a lower chance of shortage, which translates into a higher service level. V class items require a high level of service when it comes to VED analysis because they are crucial. For a decent degree of service, E class items require medium level and D class items require a tolerable level of service.

Table 2 VED Classification of Spares

Class	Number of items	% of total items
V	45	5.54
E	716	88.07
D	52	6.39
Total	813	100

Table 3 depicts those 150 items, or 18.45% of the total of 813, fell into category I. It would be easier to keep an eye on the annual budget and their availability with the management of category I items. In total, 619 items (76.14%) were classified into category II and remaining 44 items (5.41%) into category III. While category III things should be readily available with few record restrictions, class II items would be handled routinely. The materials management should devote less effort for 'CD' items because even substantial reductions in inventory costs for these items will produce only small overall savings.

Table 3 Combined classification: ABC-VED

ABC/VED Matrix	V	E	D	Total
A	12 (AV)	100 (AE)	5 (AD)	117
B	10 (BV)	77 (BE)	3 (BD)	90
C	23 (CV)	539 (CE)	44 (CD)	606
Total	45	716	52	813
Category-I	45	100	5	150
Category-II	0	616	3	619
Category-III	0	0	44	44

Table 4. Policies for items of classes A, B, and C

Class	Degree of control	Order quantity	Order frequency	Service level	Safety stocks	Review System	Inventory Turnover Ratio
A	Maximum	Small	More	Low	Low	Continuous	High
B	Modest	Medium	Intermediate	Medium	Moderate	Periodic	Medium
C	Minimum	Bulk	Less	High	Large	Single-period	Low

Following the classification of all the user-consumed spare parts for the fiscal year 2021–2022, various inventory management strategies were advised for each class of items, which, if implemented, would improve the productivity of the production unit. The materials management department was advised to order various classes of spare items and stock them in the warehouse in accordance with the policies listed in Table 4.

6. Conclusions

Cost effective spare parts management relies upon appropriate classification methodologies. This is due to highly varying nature of spare parts and the tremendous numbers by which they are represented in the relevant business contexts that necessitate a comprehensive approach to distinguish between them for ordering and stock control purposes. In the field of inventory management project at the said chemical plant, it was proposed to develop inventory classification methods based on annual consumption value and item criticality. Different policies have been suggested to take care of the ordering of items (i.e., for A, B and C). Decisions to hold those items in stock can now be based on quantitative and objective information. The transparency and the user friendliness of the classification tool can be perceived as the major advantages of the procedure. The contribution of the research work was not merely focused on the development of a theoretical classification model but rather on actual implementation of a classification method in an industrial environment. Moreover, the insights gained can be generalized towards a generic decision-making tool in similar industrial settings. We discovered during the study that it is always preferable to treat some items with preference rather than all items equally.

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