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Critical Spare Parts Identification and Management of Mechanical Ventilation and Air-Conditioning (MVAC) System in University Campus

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ABSTRACT

Spare parts are used to keep a system functioning, reducing downtime and the system's life span. Recently, spare parts management has gained significant attention among maintenance departments due to the "right to repair", which required the provision of readily available spare parts. Therefore, this study focused on identifying critical spare parts for mechanical ventilation and air-conditioning (MVAC) systems. The objectives of this study were to identify the critical spare parts needed in the MVAC system in the university campus and analyze the priority factors affecting the management of these critical spare parts. The Cartesian coordination system based on critical and important has been used to classify spare parts into four quadrants consisting of Indispensable (QA), Imperative Secondary (QB), Unnecessary (QC), and Lower Priority Required (QD). The spare part inventory management and impact of the system have also been examined to be classified into preferred, consistently managed, moderately managed, infrequently managed, and commonly managed. The Cartesian coordination analysis revealed that 19 out of 20 critical spare part components fell into a quadrant of indispensable, which implies that require much attention in the system. In contrast, one component fell within quadrant QD, indicating low importance but functional for the MVAC system. In addition, the combination matrix analysis categorized the components into five classified where 6 components were consistently managed, 11 components were moderately managed and 3 components were infrequently managed in the management of the university campus. The findings are critical for facility management to ensure the reliability and efficiency of the MVAC system and regular monitoring and optimization of spare parts, especially critical parts of the system.

Keywords: Spare part, Cartesian Coordination, Combination Matrix method, Maintenance management.

1. INTRODUCTION

Managing spare parts has become increasingly important in this generation due to the rapid advancement of technology, which has resulted in various challenges. The poor ability to predict future demand led to recurring circumstances involving both excessive stock and inadequate stock levels. The presence of technical issues can undermine the effectiveness of maintenance

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activities, especially in mechanical ventilation and air conditioning (MVAC) systems. The ventilation functions and indoor air quality (IAQ) features of MVAC systems work together to maintain a healthy and comfortable indoor environment [1]. Regular maintenance is important to ensure system reliability and occupant comfort [2]. With growing populations and rapid technological developments, the demand for MVAC systems has increased [3]. Most modern buildings are enclosed and rely on these systems for proper ventilation and thermal comfort. Since people spend around 80% of their time indoors, indoor air quality has become important for human health and well-being. In commercial buildings, MVAC systems can use up to 40% of the total energy, making them a key part of daily operations [4]. Therefore, improving their energy efficiency is an important goal for building managers and stakeholders.

Spare parts are critical for system stability and include component parts, equipment, and supporting elements that must be replaced. Replacing faulty components with relevant spare parts may lower operational costs. Reusing spare parts is also a cost-effective method that reduces the financial strain of obtaining new components [5, 6]. Proper management was involved in purchasing the right quantity and quality at the right time while adhering to cost constraints. Managing spare parts inventory has many challenges, especially for MVAC systems. Inaccurate demand forecasting leads to overstocking or shortages, causing high costs or system failures [5]. Supply chain disruptions, dependency on limited suppliers, and long lead times further complicate inventory management, making it hard to ensure the timely availability of critical parts [2].

Poor spare parts management resulted in operational inefficiency, financial losses, and system unreliability. Operations at the facility were interrupted, and productivity decreased because of prolonged equipment downtime due to a lack of available parts [5]. The lack of inventory planning among these organizations produced both budgetary problems and wasted resources, and unnecessary procurement expenses [1]. Establishing effective relationships with suppliers was the key factor to minimizing stockout risks and ensuring prompt inventory refreshment [7]. The implementation of digital inventory systems resulted in streamlined stock tracking, automated reordering, and improved spare parts availability, all while reducing unnecessary costs. [10>8].

The spare parts management posed specific challenges for universities that operated large MVAC systems. A continuous supply of dependable spare parts was essential to keep classrooms, laboratories, and offices functional in a comfortable learning setting [1]. Failure in inventory control produced unanticipated MVAC failures, which led to increased repair expenses and disrupted operations. [2] The universities faced financing constraints stopping them from building proper stock levels of crucial replacement components even though they needed affordable maintenance approaches [3]. Centralized inventory management helped universities avoid stock shortages and unnecessary purchases. [8]. Companies that worked with reputable suppliers kept supply chains stable, lowering procurement delays and effectively managing their expenses [9]. Effective spare parts management strategies ensured sustained and cost-efficient maintenance operations for institutions.

Technological advancements have highlighted the importance of effective spare parts inventory management. However, challenges such as overstocking often arise due to inaccurate demand forecasting. Excess inventory can hinder the timely availability of essential components and lead to increased maintenance costs [10]. The findings are intended to contribute to more efficiency in spare parts management, particularly in the context of MVAC systems within educational institutions.

2. METHODOLOGY

The methodology started with the process of collecting spare part data from the most up-to-date and appropriate source for review from the maintenance department. To ensure the quality of this study, the process of identifying the critical spare parts inventory management of MVAC systems is required. Figure 1 illustrates the methodology used in this study. The first step was to collect data on critical spare parts of the MVAC system. Subsequently, a questionnaire was distributed to obtain feedback on the critical spare parts. After collecting the data, it was analyzed through two main methods. The first method was the Cartesian Coordination System, which was used to classify spare part components based on importance and urgency. The second method was the matrix combination method, which helped support effective decision-making in management.

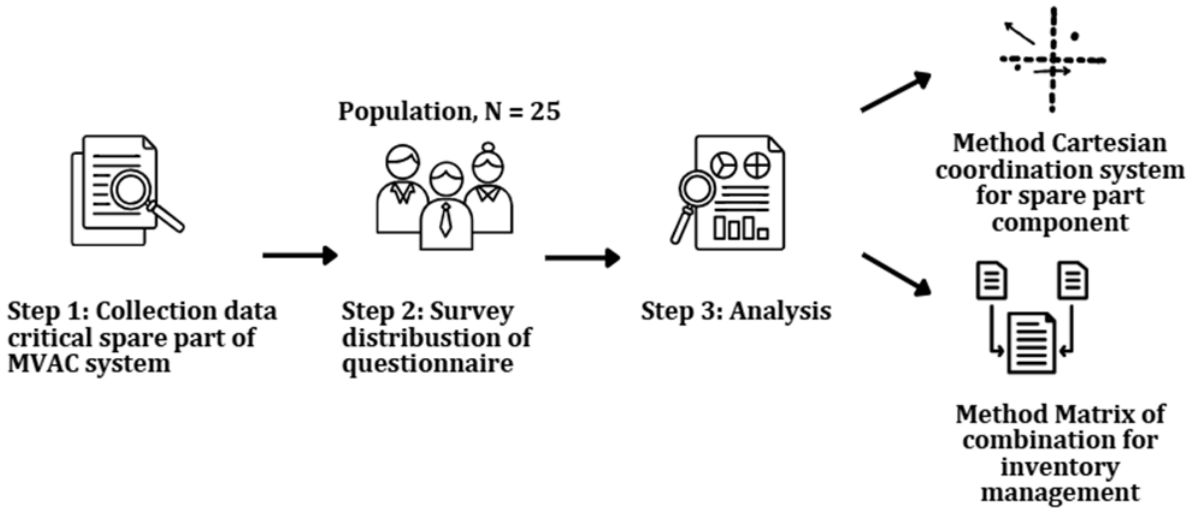

Figure 1: Process of methodology.

2.1 Collection data critical spare parts of MVAC system

The Universit Tun Hussein Onn (UTHM) Campus Pagoh was selected for data collection in this case study. The maintenance department provided data on critical components of the MVAC system, including Air Handling Units (AHU), Fan Coil Units (FCU), and cassette units. A total of 20 critical spare part components were identified and incorporated into a questionnaire for feedback collection. The analysis focused on component failures and replacements that occurred most frequently. Data on component types and the quantity of replacements or damages were recorded from 2017 to 2024. The evaluation sought to uncover important equipment parts that required ongoing maintenance. The study of components with frequent breakdowns enabled a better assessment of alternative parts that provided improved reliability. The obtained data provided essential information about replacement requirements, which helped develop plans for spare part inventory. The approach improved maintenance efficiency by ensuring prompt accessibility of parts needed for AHU, FCU, and cassette units.

2.2 Respondents of survey

The questionnaire was distributed to several respondents to gather feedback on the management of the critical spare parts in the MVAC system and the importance of prioritizing critical spares. It was divided into three sections. Section A consisted of respondents' demographics, including name, contact information (email/phone number), age, location, department, responsibilities, job role, and working experience. Section B pertained to critical spare parts that frequently malfunctioned in the MVAC system, aiming to understand the importance of the listed spare parts. Lastly, section C addressed factor analysis concerning spare part inventory management of the MVAC system, focusing on parts that have frequently been damaged and aimed to ascertain the impact on the system.

The respondents targeted for this study were individuals responsible for managing or maintaining the MVAC systems at UTHM Campus Pagoh, including engineers, contractors, subcontractors, and technicians from various external companies. The sample size was an important aspect of quantitative research to ensure the validity and reliability of the results. One commonly used method in surveys was Slovin's formula, as shown in Equation (1). It determined the number of respondents needed based on a known population while considering the margin of error. Slovin's formula provided an estimate of the sample size (n) based on the population size (N) and the acceptable error value (e) [11]. The sample size for a particular study was determined by the resulting value of n.

$$n = \frac{N}{1+Ne^2} \tag{1}$$

Where:

n is the required sample size
N is the total population
e is the margin of error

Proportional allocation was then employed to select participants from the UTHM Department of Maintenance and collaborating companies based on Table 1.

Table 1: The population using Slovin's Formula.

Subgroup	Population (N)
Engineers	9
Contractors	4
Subcontractors	4
Technicians	10
Total Population	27
Total sample size	25

2.3 Cartesian coordination system

After obtaining questionnaire data through analysis, the Cartesian coordinate system method classified spare parts based on criticality and importance. This method, modified by the author, identified the Critical Success Factors when developing strategies that maximize the customer's potential [12]. A Cartesian coordinate system was used in the method, with criticality on the x-axis and importance on the y-axis. The use of scale remained the same, 1 to 5 for measuring the importance part; for performance, this research converted to critical but still used a scale 1 to 5. Each quadrant of the system was labeled with a description of the spare parts that would fall into that category, as shown in Table 2.

The classification of spare parts occurred according to their assigned criticality and importance scores. Based on Figure 2, spare parts critical to the operation of a piece of equipment and important for maintaining production were classified as "indispensable" and fell into the upper right quadrant of the chart. Required spare parts share the upper left quadrant of the chart since they are essential for production maintenance, although they do not affect equipment operation. Maintenance organizations can utilize this method as a helpful tool to ensure smooth workflow.

It was possible for it to make informed decisions about which spare parts to stock by classifying them based on criticality and importance.

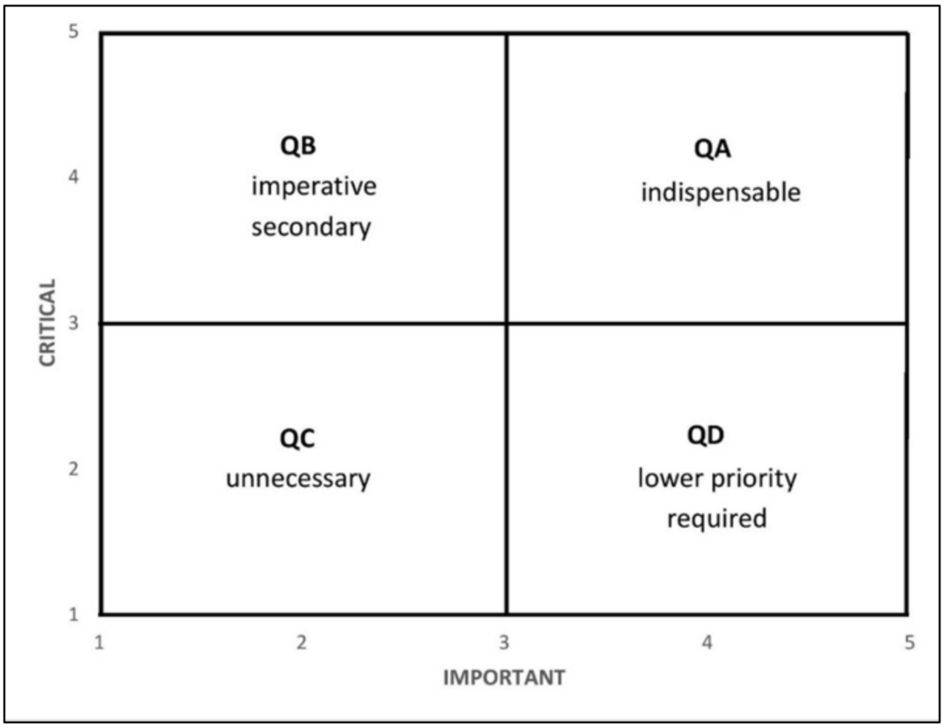

Figure 2: Critical vs Important Matrix.

Therefore, in Table 2 the Cartesian system obtained four quadrants that allowed set out four distinct criteria:

Table 2: Section in quadrant.

Quadrant	Criteria
QA	Indispensable (high important/high critical spare part)
QB	Imperative secondary (high important/low critical spare part)
QC	Unnecessary (low important/low critical spare part)
QD	Lower priority required (low important/high critical spare part)

2.4 Matrix of combination

The analysis matrix of combination evaluated the management of spare parts inventory, which impacted the system if not addressed properly. The method employed and analyzed the quantity to order of spare parts and the safety stock value based on information provided by machine suppliers and the maintenance department's experience [13]. While this study used 5 concepts: preferred, consistently managed, moderately managed, infrequently managed, and commonly neglected. For the criteria section, two criteria were processed from two criteria: function and production impact from modified research, for this study management, and system impact the inventory management criteria.

In this study, there were five types for every criterion listed. Two criteria, namely system management and impact, were created. Inventory management was divided into five stages, and impact systems were divided into six stages. Table 3 describes the level of the criteria.

Table 3: List description of criteria.

Criteria	Description	References
Management		
1. Maintenance management	Low spare parts inventory disrupts operations.	[27]
2. Maintaining high stock level	Holding excessive spare parts increases costs and ties up capital.	[3]
3. High cost	High spare parts costs, budget, and finances.	[5]
4. Delays in management	Delays in procurement, delivery, or maintenance increase downtime and disruptions.	[28]
5. Out of stock	Optimize equipment and parts for durability and peak performance with strategic procedures.	[29]
System Impact		
0. No impact	The spare part failure has no direct impact on system operation or performance.	[30]
1. Quality losses	Failure leads to defective products, impacting system quality.	[14]
2. Productivity reduction	Failure lowers system productivity, making it less efficient or slower.	[30]
3. Sudden stoppage	The part breaks, the system stops and needs a quick fix to restart.	[28]
4. Partial system shutdown	Partial spare part failure disrupts system functions.	[31]
5. System downtime	Spare part failure increases downtime, leading to production losses, higher costs, and delays.	[32]

After selecting the criteria and levels, it was verified that both criteria had the same importance. Therefore, the levels of management criteria were ordered starting from 1 while the system impact criterion levels proceeded from 0 to 5, as shown in Table 3. In both cases, the levels were assigned numbers beginning with the lowest importance at the smallest number. The first step led to assigning 5 levels of inventory management: preferred, consistently managed, moderately managed, infrequently managed, and commonly neglected. Figure 3 presents a matrix of combination criteria and level pairings that this study used for the analysis.

Figure 3: Matrix of combination.

3. Result

The demographic data has been collected from 27 respondents. Most of the respondents were men, 70.4%, and above the age of 32 years, 51.9%. Among the respondents, 18.5% were employed at Company A, while the remaining 18.5% were in Company C. Regarding the departments they belonged to, the technician group was the biggest, with 37%, while engineers comprised 33.3%. According to work experience, most of the respondents were at a senior level, which was the sample of experienced people who gave the right information. Table 4 shows the demographic profile of the respondents.

Table 4: Demographic profile (n=27).

		Count	N %
Gender	Male	19	77.4
	Female	8	29.6
Age	20-25 years	3	11.1
	26-31 years	10	37.0
	32 years above	14	51.9
Company	Company A	5	18.5
	Company B	4	14.8
	Company C	5	18.5
	Company D	2	7.4
	Company E	2	7.4
	Company F	4	14.8
	Company G	1	3.7
	Company H	1	3.7
	Company I	3	11.1
Position	Engineer	9	33.3
	Technician	10	37.0
	Contractors	4	14.8
	Subcontractors	4	14.8
Working Experience	Junior	2	7.4
	Mid-level	10	37.0
	Senior	15	55.6

Table 5 shows a good response rate. Cronbach's alpha measured the reliability of data where values above 0.7 were considered acceptable, and those exceeding 0.8 indicated good internal consistency [15]. The results showed good reliability, with Cronbach's alpha value of 0.828 for important component spare parts and 0.831 for system impact on the MVAC system. The critical component spare parts and inventory management criteria were acceptable, with values of 0.792 and 0.783, respectively.

Table 5: Cronbach's alpha reliability critical component spare part inventory management.

Variable	Cronbach's alpha
Critical component spare part	0.792
Important component spare part	0.828
Inventory management criteria spare part	0.783
System impact on MVAC system	0.831

3.1 Critical spare part usage by year

Spare parts were indispensable for the MVAC system of the UTHM Campus Pagoh for reliability, efficiency, and comfort level of occupants. The focus was on the generally used parts, such as the air handling unit (AHU), fan coil unit (FCU), and cassette unit. Table 6 shows that spare part usage from 2017 to 2024 revealed that various key components had different demand patterns. The usage of motorized valves remains high, with 18 pieces sold in 2019 and 2022, and the usage of capacitors (5μF and 30μF) decreased after 2020. Blower motors also presented moderate cyclic patterns, with the most usage identified in 2017 and 2024.

Table 6: Table of spare part usage by years.

Component	System	2017	2018	2019	2020	2021	2022	2023	2024
Motorized Valve	FCU	10	18	5	6	10	9	6	5
Capacitors (5μF)	FCU	2	8	3	3	3	5	3	3
Capacitors (30μF)	FCU	1	5	2	2	2	2	2	2
Controller (BMS)	AHU	5	7	4	4	8	6	6	6
Thermostat Sensor	FCU	3	6	2	5	4	4	5	5
PCB Board (2.5HP)	Cassette unit	4	4	3	4	5	3	4	4
PCB Board (3HP)	Cassette unit	6	6	4	5	6	4	5	5
PCB Board (5HP)	Cassette unit	2	3	2	3	3	2	3	3
ELCB	AHU/Cassette unit	4	5	1	1	4	3	2	2
MCB (10A)	AHU	3	4	6	2	5	6	7	7
MCB (16A)	AHU	2	3	4	3	2	3	4	4
MCB (32A)	Cassette unit	1	2	2	1	1	1	2	2
Cassette Unit	Cassette unit	7	9	8	5	7	7	8	8
Blower Motor	FCU	3	7	3	4	4	5	4	4
Water pump (42TNC0324W)	AHU	2	3	4	3	3	2	3	3
Water pump (42TNC036W)	Cassette unit	1	2	3	2	2	1	3	3
Filter (Cotton)	FCU/Cassette unit	5	5	1	1	6	4	1	1
Filter (Paper)	AHU	4	4	1	2	5	3	1	1
Bearings	FCU	3	6	2	2	4	3	2	2
V-Belting	AHU	2	3	1	3	3	2	2	2

The most frequently ordered spare part was the motorized valve, with a total of 69 units; it is considered a critical spare part in inventory. Another component used frequently was the capacitor (5μF), and the capacitor (30μF) used 50 units and 30 units, respectively. Among the lots, most units were recorded from the side of the blower motor, with 29 units underlining its importance. However, the next-lowest total of 9 units was assigned to the thermostat sensor, which was also considered one of the least important parts.

3.2 The cartesian coordination

Based on the feedback from the survey in Table 7, the components were arranged according to the mean scores, standard deviations, and rankings. The blower motor was identified as the most critical component in the MVAC system. A failure in the blower motor would lead to operational disruption and the potential for significant productivity loss in the MVAC system [16]. The water pumps, such as models 42TNC0324W and 42TNC036W, were ranked second and third. A failure in the water pumps could result in overheating, system damage, and operational disruption in the system [17]. The last three rankings were for the Earth Leakage Circuit Breaker (ELCB), capacitors, and thermostat sensors. A failure in these three components typically does not result in an immediate system shutdown. The study suggested that spare parts with minimal failure impact on the main system were given lower priority in critical spare parts management [18].

Table 7: Critical of the component spare parts.

Component	Mean	Std. Deviation	Ranking
Blower Motor	4.33	0.88	1
Water pump (42TNC0324W)	3.78	1.19	2
Water pump (42TNC036W)	3.78	1.19	3
V-Belting	3.74	1.23	4
Bearings	3.70	1.30	5
PCB Board (5HP)	3.70	1.20	6
PCB Board (2.5HP)	3.63	1.24	7
MCB (32A)	3.56	1.22	8
Controller (BMS)	3.56	0.98	9
Cassette Unit	3.52	1.34	10
PCB Board (3HP)	3.48	1.16	11
MCB (16A)	3.48	1.09	12
Motorized Valve	3.41	1.25	13
Filter (Paper)	3.37	1.39	14
Capacitors (5μF)	3.37	1.28	15
Filter (Cotton)	3.33	1.41	16
MCB (10A)	3.33	1.14	17
Capacitors (30μF)	3.26	1.23	18
ELCB	3.26	1.16	19
Thermostat Sensor	2.56	1.12	20

As highlighted in Table 8 below, the importance of the spare parts in the component showed the ranking. The blower motor was ranked first in both tables and was an important component that ensured efficient air distribution in the system. The controller or building management system (BMS) was in second place, and it played a vital role in controlling and monitoring the overall operation of the MVAC system. The third rank was held by the bearing component, which functioned to support the movement of rotating components such as motors and blowers. The 18th and 19th ranks were the two types of filters used to purify the air in the MVAC system. The last component ranked was the thermostat sensor, which was used for temperature control in the system. The management strategy for spare parts should concentrate on essential elements like the blower motor and BMS together with bearings, but filters and thermostat sensors rank as lower priorities.

Table 7 and Table 8 show that the entire chart was categorized into four sections, QA, QB, QC, and QD, depending on their analysis in terms of critical and important factors. Figure 4 shows that the analysis concluded that 19 out of 20 critical spare part components fell into quadrant QA because most elements scored high in both critical and important factors in the MVAC system. Meanwhile, the remaining component fell into quadrant QD, as it was a component with low critical but high importance for the MVAC system.

Figure 4 illustrates the quadrant analysis for 19 critical spare components that fell into the QA quadrant. The items found in this area were motorized valves, capacitors (5μF and 30μF), controllers (BMS), PCB boards (2.5HP, 3HP, 5HP), ELCB, MCB (10A, 16A, 32A), cassette units, blower motor water pumps (42TNC0324W, 42TNC036W), filters (cotton, paper), bearings (40LM150/200), and V-belting (40LM150/200). All these components were considered critical in terms of function but were not categorized as immediately needed. The only component that fell into the QD quadrant was the thermostat sensor. This was due to the component being considered less critical in the MVAC system. This was because the thermostat sensor rarely failed, and its impact on operations was not as significant as other components. This analysis helped in understanding the components that required more attention in terms of availability and inventory monitoring.

Table 8: Importance of the component spare parts.

Component	Mean	Std. Deviation	Ranking
Blower Motor	4.37	0.79	1
Controller (BMS)	4.22	0.75	2
Bearings	4.15	1.10	3
V-Belting	4.11	1.12	4
MCB (32A)	3.93	1.00	5
Capacitors (30μF)	3.93	0.83	6
Capacitors (5μF)	3.89	0.89	7
Motorized Valve	3.89	0.89	8
PCB Board (5HP)	3.85	0.91	9
Cassette Unit	3.81	1.04	10
Water pump (42TNC0324W)	3.81	1.04	11
PCB Board (3HP)	3.81	0.88	12
Water pump (42TNC036W)	3.78	1.01	13
ELCB	3.74	1.10	14
MCB (16A)	3.74	1.10	15
MCB (10A)	3.70	1.17	16
PCB Board (2.5HP)	3.70	0.95	17
Filter (Paper)	3.63	1.24	18
Filter (Cotton)	3.59	1.22	19
Thermostat Sensor	3.22	1.12	20

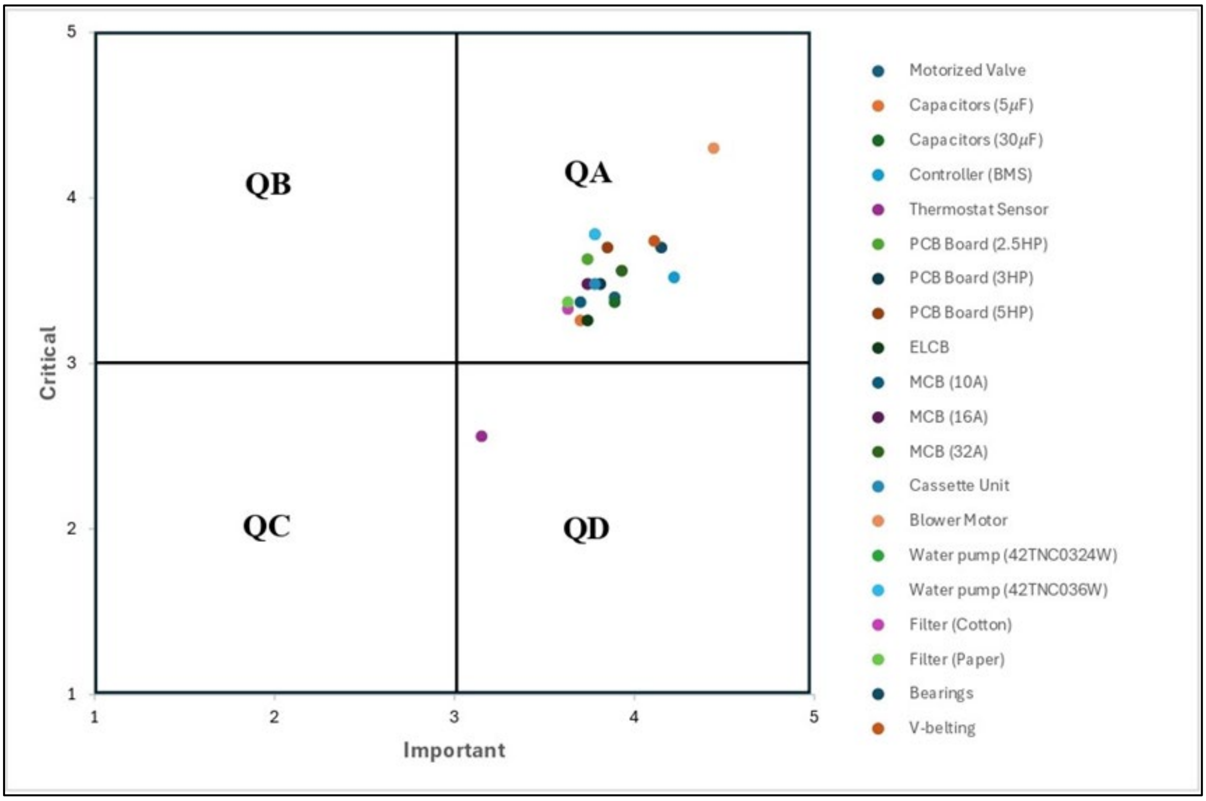

Figure 4: Analysis of the quadrants for the critical component spare parts.

3.3 The matrix combination

A combination matrix was used where it was necessary to contrast and analyze one or more items in relation to several criteria. Table 9 shows two data points that reflect inventory management and evaluation conclusions and their impact on the system. Some of the issues faced with managing critical spare parts are delivery delays, situations whereby the spare part has run out of stock, high costs, and high maintenance demands. Focused on inventory challenges where the company provided basic mean values and standard deviations of 20 components to illustrate availability and variability.

Table 9: Inventory management vs. System impact of the component spare part inventory management.

	Inventory management		System impact	
Component	Mean	Std. Deviation	Mean	Std. Deviation
Motorized Valve	3	1.19	3	1.67
Capacitors (5μF)	3	1.32	3	1.48
Capacitors (30μF)	3	1.53	3	1.48
Controller (BMS)	2	1.34	3	1.33
Thermostat Sensor	2	1.18	1	1.35
PCB Board (2.5HP)	3	1.34	3	1.62
PCB Board (3HP)	3	1.32	4	1.40
PCB Board (5HP)	3	1.19	4	1.40
ELCB	3	1.54	3	1.58
MCB (10A)	3	1.50	3	1.57
MCB (16A)	3	1.51	3	1.40
MCB (32A)	3	1.19	4	1.25
Cassette Unit	3	1.42	2	1.63
Blower Motor	3	1.03	4	1.14
Water pump (42TNC0324W)	3	1.03	4	1.14
Water pump (42TNC036W)	3	1.34	4	1.22
Filter (Cotton)	3	1.18	1	1.05
Filter (Paper)	3	1.18	1	1.08
Bearings	3	1.34	3	1.69
V-Belting	3	1.32	3	1.68

This classification method was used to determine the position of spare parts based on inventory management levels. A five-category system categorized components based on inventory management status: preferred, consistently managed, moderately managed, infrequently managed and commonly neglected. Table 10 shows that infrequently stored components, such as the thermostat sensor and filters (cotton and paper), were critical to system operation but had minimal criticality. They were managed with little oversight and just-in-time restocking. Other components, such as the motorized valve, capacitors (5μF and 30μF), controller (BMS), PCB board (2.5HP), ELCB, MCB (10A and 16A), cassette unit, bearings, and V-belting, were moderately managed with basic inventory practices and periodic reliability reviews. The consistently managed components for system operations included PCB boards (3HP and 5HP), ELCB, MCB (32A), blower motor, and water pumps (42TNC0324W & 42TNC036W Advanced inventory controls and risk management strategies together with reviews served to proactively maintain these components for sustaining system operations.

The analysis showed that the major parts of the organization were well-maintained in terms of critical components, with most parts remaining stable at a consistently managed level and a few parts at a moderately managed level. The distribution between these two categories demonstrated an understanding of the importance of the components and the effort made to ensure reliability in the assembly [19]. Through this system, the equipment reduced risks of failure and time without operation for important elements, including valve controllers and PCB boards. The parts that were managed moderately, including capacitors and bearings, were also examined, though with slightly less attention due to their moderate effects [20]. By applying this classification system, components were given attention proportionate to their importance and function within the system.

Table 10: Critical component spare part classification.

Component	Inventory management	System impact	Sum	Classification
Motorized Valve	3	3	6	Moderately managed
Capacitors (5μF)	3	3	6	Moderately managed
Capacitors (30μF)	3	3	6	Moderately managed
Controller (BMS)	2	4	6	Moderately managed
Thermostat Sensor	2	1	3	Infrequently managed
PCB Board (2.5HP)	3	3	6	Moderately managed
PCB Board (3HP)	3	4	7	Consistently managed
PCB Board (5HP)	3	4	7	Consistently managed
ELCB	3	3	6	Moderately managed
MCB (10A)	3	3	6	Moderately managed
MCB (16A)	3	3	6	Moderately managed
MCB (32A)	3	4	7	Consistently managed
Cassette Unit	3	3	6	Moderately managed
Blower Motor	3	4	7	Consistently managed
Water pump (42TNC0324W)	3	4	7	Consistently managed
Water pump (42TNC036W)	3	4	7	Consistently managed
Filter (Cotton)	3	1	4	Infrequently managed
Filter (Paper)	3	1	4	Infrequently managed
Bearings	3	3	6	Moderately managed
V-Belting	3	3	6	Moderately managed

4. Discussion

Combination of the Cartesian Coordination System and Matrix Combination method, the stock management of critical spare parts for MVAC systems at the campus UTHM campus Pagoh was done efficiently. The Cartesian Coordination System method worked to classify and prioritize spare parts according to how critical they were towards the system, and it would affect the system if the spare parts were used. The Matrix Combination method enriched the assessment by categorizing the inventory components according to out-of-stock risks, high stock and costs, delays, and their impact on system performance. The integration of these two methods produced a systematized appraisal of inventory concerns and mechanics [21].

Based on the analysis in Table 10, components such as the PCB boards (3HP and 5HP), ELCB, MCB (32A), blower motor, and water pumps (42TNC0324W & 42TNC036W) were identified as critical for inventory management. These components were placed in the QA quadrant of the Cartesian graph, indicating they were both highly important and critical, as shown in Figure 4. This was linked to system downtime, as losing these components significantly impacted operations. System downtime combined with production losses accompanied by higher maintenance expenses and repair costs would result from component failure [22]. This highlighted the need for high inventory levels to ensure the system remained operational. System breakdowns were avoided by consistent management practices which allocated priority to spare parts [23].

Most components were categorized as moderately managed, including the motorized valve, capacitors (5μF and 30μF), controller (BMS), PCB board (2.5HP), ELCB, MCB (10A and 16A), cassette unit, bearings, and V-belting. These components were in the QA quadrant but were less critical than the consistently managed items. As shown in Figure 4, their failure did not cause system outages but led to inefficiencies or minor disruptions, impacting productivity [24]. Capacitors responsible for energy storage could be temporarily bypassed in case of failure. The management implemented a system to optimize inventory levels, which meant keeping costs low but never running out of necessary stock. The importance of holding strategies for less critical inventory to balance costs and operational reliability [25].

Table 10 shows that consumables like thermostat sensors and filters (cotton, paper) used in MVAC systems are classified as infrequently managed inventory components. Despite being infrequently managed, filters are crucial and valuable, falling under the QA quadrant in the Cartesian coordination method. Thermostat sensors are categorized in the QD quadrant due to their lower criticality, but they are still necessary for the MVAC system function [26]. The filters affect system quality in air conditioning and purification, contributing to quality losses. Thermostat sensors serve as temperature monitors, and system disruptions may result from delayed maintenance activities or sensor replacement [33].

Figure 4 and Table 9 show that the Cartesian Coordination System and Matrix Combination gave 19 of 20 component values in the QA quadrant, with one in the QD quadrant. None of them were classified in QB or QC, indicating that the items reported meet the minimum inventory management and operation relevance level standard. The approach ensured that all parts of the system received enough attention irrespective of their size, improving reliability by considering the cost.

5. Conclusion

The study evaluated the importance of identifying critical spare parts for maintaining the optimal operation of the MVAC system, focusing on the AHU, FCU, and cassette unit at the UTHM Campus Pagoh. This systematic approach not only focuses on essential components but also on understanding operational significance, emphasizing the need for proactive inventory management. In the combination analysis for the Cartesian coordinate system and matrix combination, spare parts were ranked according to their criticality and importance. Categorizing these priority factors led to more informed inventory management decisions, emphasizing that a clear understanding of these elements was essential for improving operational efficiency and preventing MVAC system disruptions. Failure to address these factors resulted in increased maintenance costs, longer downtimes, and a detrimental impact on user comfort and satisfaction.

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