
CHAPTER 2 – LITERATURE REVIEW

In this study, we will discuss the literature review, which includes topics such as RCM, Failure Mode and Effect Analysis (FMEA), critical spare part management, Economic Order Quantity, ABC Analysis, VED, FSN, Multi-Criteria Analysis Decision Making, AHP, and other relevant subjects related to determining the criticality of spare parts.

2.1 Reliability Centred Maintenance (RCM)

Reliability Centred Maintenance (RCM) employs a systematically method to formulate maintenance strategies by considering variables such as the lifespan of the system, operational effectiveness, and cost-effectiveness of maintenance. (Yang et al., 2020). The objective is to reduce the necessity of repairing building flaws through improved planning and execution, the use of appropriate materials and tools at the right moment, and minimizing the overall Life Cycle Cost (LCC) (Ali et al., 2010). The RCM approach is a targeted approach that links preventive measures to the reliability and cost limitations of the component and grid. (Moradi et al., 2018). It has been implemented using vibration analysis as a condition-based monitoring technique (Sarje, 2018). RCM has also been applied to improve the reliability of production processes and maintain production continuity in various industries, including a chemical plant (Syamaun et al., 2023).

In the context of materials, parts, and inventory management, RCM plays a crucial role in enhancing maintenance performance by allocating and coordinating resources such as spare parts in order to enhance the overall reliability, safety, operational capabilities, financial feasibility, level of comfort, and ease of use, there is a constant need for continuous improvement and refinement. (Au-Yong et al., 2016). The quality of spare parts and materials, as well as inventory control, are significant characteristics for scheduled maintenance, while the reliability of maintenance data and financial allocation for the maintenance manager are dominant characteristics for condition-based maintenance (Au-Yong et al., 2014). Moreover, the maintenance activity generates tacit knowledge based on experience, which is crucial for knowledge management in maintenance engineering (Carrasco et al., 2020). However, it is crucial to acknowledge that the guidelines for

managing maintenance spare parts should be different from product inventory management (Gomes et al., 2020).

RCM is a comprehensive strategy that not only focuses on maintenance optimization but also integrates with materials, parts, and inventory management to enhance overall maintenance performance and reliability.

2.2 Failure Mode and Effect Analysis (FMEA)

One of the key tools used in RCM is the Failure Mode and Effects Analysis (FMEA) (Peeters et al., 2018). FMEA is utilized to identify the components, failure modes, and underlying causes that are most relevant for system reliability and availability (Selim et al., 2015). It is carried out with a diverse team to ensure the identification of all possible failures and proper estimation of their effects (Peeters et al., 2018). FMEA is also used to analyse the causes of damage, the impact, and effective measures for equipment, making it an essential part of RCM (Priyanta et al., 2019).

FMEA is a systematic approach to identifying and preventing potential failures in a system or process by analysing the effects of each potential failure mode and determining the likelihood of its occurrence as shown in Figure 3.

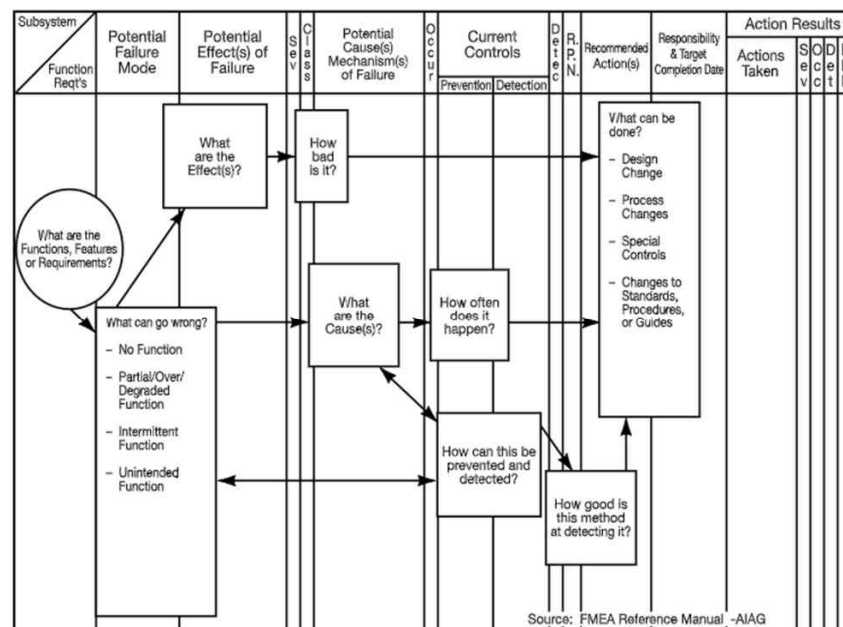


Figure 3. FMEA Sheet with steps (Gulati, 2009)

The producer of the equipment and systems typically provides a suggested inventory of replacement components and a proactive maintenance schedule derived from a Failure Modes and Effects Analysis (FMEA).

The failure modes and its frequency of failures identified through FMEA can assist in refining the spare parts list and provide a reliable estimate of the types and quantities of parts and materials needed to be stocked during a specified period. By stocking the right parts and materials in the right quantity, organizations can minimize downtime and reduce maintenance costs. (Gulati, 2009)

Regularly reviewing and updating the spares list is crucial to account for changes in the system or process, along with fluctuations in the availability and cost of parts and material. In addition to the manufacturer's recommendations, organizations can also use historical data on equipment failures and maintenance activities to refine their spares list and improve their stocking strategy. (Gulati, 2009)

2.3 Failure Mode Effect and Criticality Analysis (FMECA)

Failure Mode, Effects, and Criticality Analysis (FMECA) is a widely adopted approach for assessing and mitigating potential failures in various systems and processes. It involves a structured methodology to identify failure modes, their causes, and the effects on the system or equipment (Borgovini et al., 1993). FMECA is used in diverse fields such as aerospace, medicine, electronic devices, and energy equipment. The technique was initially developed for military purposes to assess the reliability of technical systems. FMECA is an extended version of Failure Mode and Effects Analysis (FMEA) and incorporates criticality analysis to provide a quantitative estimation of the criticality of identified failures. The application of FMECA involves both qualitative hazard analysis and quantitative assessment of critical subsystems. Additionally, FMECA has been applied in the context of reliability engineering, where it aids in predicting and analysing the reliability of systems and components. Furthermore, FMECA has been utilized in the development of maintenance management strategies and in optimizing human safety by minimizing the occurrences of failures (Zafiropoulos et al., 2005)

2.4 Critical Spare Part Management

Critical Spare Part Management is a strategic approach to managing spare parts for essential and high-value assets or equipment within an organization. These critical spare parts are vital components that, if not available when needed, can cause significant disruptions to production, operations, or services.

Referring to Dekker et al. (1998), who defined 'criticality' as the extent of importance of specific equipment in maintaining safe and efficient production, one can use an equipment criticality classification to identify crucial spare parts that demand additional attention and must be maintained in inventory to ensure uninterrupted production. To practically determine criticality, two classification approaches can be applied: 'quantitative methods' like ABC and FSN analysis as shown in Figure 4, which rely on numerical values, and 'qualitative methods' such as VED analysis, which assign criticality levels based on subjective judgments or scoring methods.

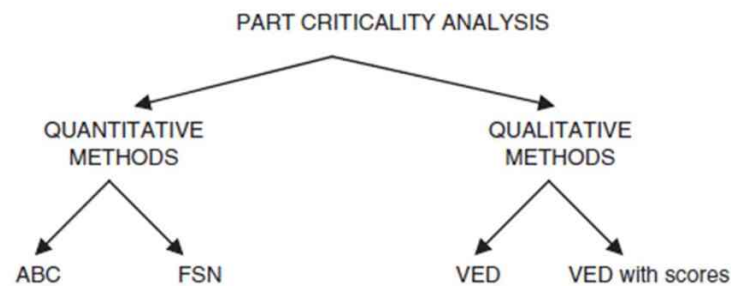


Figure 4. Method for Spart parts criticality Analysis (Cavalieri et al, 2008)

2.5 Economic Order Quantity

The Economic Order Quantity (EOQ) is a calculation utilized in inventory management to ascertain the most advantageous order quantity that reduces total inventory expenses. The EOQ model has proven beneficial in resource optimization, thereby minimizing associated costs.

The EOQ model considers two primary cost categories,

1. **Holding Costs:** These encompass expenses linked to the storage and retention of inventory, including warehousing, insurance, obsolescence, and the opportunity cost associated with tying up capital in inventory.

2. Ordering Costs: These involve the expenses incurred with each order placement, comprising administrative costs, transportation, and any other costs associated with the procurement process.

Ordering and holding costs are the most significant, and inventory costs remain constant. Minimizing ordering and holding costs will minimize overall costs. Fewer orders result from larger order quantities, but holding costs increase with a higher average inventory count.

The EOQ formula is as follows:

$$EOQ = \sqrt{\frac{D \cdot S}{H}} \quad \text{Eq. (2.1)}$$

Where:

EOQ = Economic Order Quantity (units/pcs/set/lot)

D = Annual demand (units/pcs/set/lot)

S = Ordering cost per order (US Dollar)

H = Holding cost per unit per year (US Dollar)

The objective of EOQ (Economic Order Quantity) is to ascertain the optimal order quantity that minimizes the overall inventory costs.

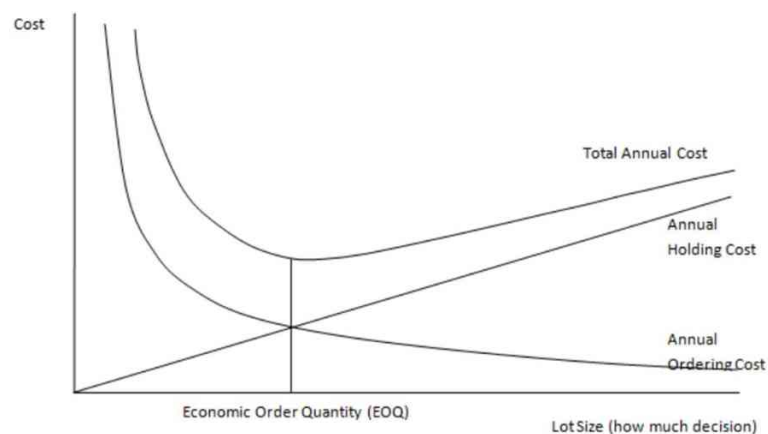


Figure 5. Economic Order Quantity and Total Annual Cost (Agarwal, 2014)

Figure 5 exhibits the primary goal of inventory management is to avoid the excessive retention of stock, as problems arising from either excessive or insufficient stock levels can lead to setbacks for any business. (Agarwal, 2014)

2.6 ABC Analysis

The ABC inventory control method operates on the principle that a limited number of items contribute significantly to overall material usage, whereas a vast number of items represent only a small fraction of the store's value. Determining the total material usage involves multiplying the quantity and unit price of each item. (Sunil, 2018)

The ABC analysis is an inventory management technique employed to classify items according to their significance and value (Nirmala, 2021), It involves dividing inventory into three categories: A, B, and C, with A items being the most important and C items being the least important. This classification helps in prioritizing inventory control and management efforts (Syrkebai,2021).

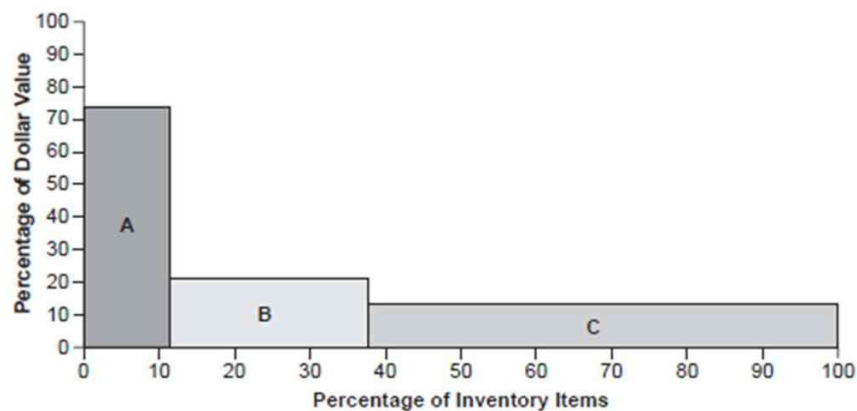


Figure 6. ABC Analysis (Gulati, 2009)

Figure 6 exhibits items in classification A predominantly consist of unique parts, and these items are usually the most crucial, with their demand being challenging to anticipate. The absence of these items can lead to prolonged periods of downtime or shutdown. Maintaining a well-regulated inventory is imperative to ensure the availability of these critical items. Research indicates that the proportion of items falling within this category typically varies from 10 to 20% of the total, with an average of 15%. Despite their

relatively lower quantity, their associated costs can encompass a substantial 60 to 80% of the entire inventory cost. Class B items, characterized as standard parts, can be stored in vendor warehouses and made accessible by local distributors within a matter of days or weeks. These items are of lesser significance, used infrequently, and their future demand can be reasonably predicted with some effort. Studies reveal that the percentage of items classified as B usually falls within the range of 20 to 35%, averaging at 25% of the total inventory items. Their corresponding costs range from 15 to 25% of the overall expenditure. (Gulati, 2009)

The majority of items classified as C consist of standard parts readily available from vendors on a consistent schedule or local distributors within a short timeframe, typically a few hours or days. Observations indicate that this category constitutes 55-75% of all items, with an average of 65%. Additionally, the cost associated with these items spans from 5-15% of the total costs (Gulati, 2009)

ABC analysis can be used in conjunction with other techniques such as VED (vital, essential, and desirable) and FSN (fast, slow-moving, and normal) analysis to further optimize inventory control. The aim is to ensure efficient utilization of resources and minimize costs while meeting customer demand. Various mathematical models and regression-based approaches have been proposed to determine the weights for ABC analysis. Overall, ABC analysis is a valuable tool for effective inventory management and control. (Syrkebai,2021) (Nirmala et al., 2021).

2.7 VED Analysis

The VED categorization system is a widely recognized qualitative approach. VED analysis is a method of categorizing items based on their level of importance. (S. Cavalieri et al. 2008). The categorization of items in VED analysis comprises three groups, specifically, Vital, Essential, and Desirable.

The category of essential items is encircled by items that prevent the unavailability of goods on the production line. Items in the required group consist of those with high stock

costs, while items in the desirable group do not lead to immediate production loss or significant disruption for short periods. Various logic can be employed to categorize a spare part in the context of VED analysis. For instance, if the absence of an equipment inhibits a production process with no standby equipment available, it qualifies as Vital. If the same item is supported by a standby unit, it falls into the Essential category. Items that have no impact on the process or safety are classified as Desirable. Despite its apparent simplicity, structuring a VED analysis can be challenging, as it relies on subjective judgments. To mitigate this challenge, VED can be integrated with a systematic approach for spare part classification. (Cavalieri et al. 2008).

2.8 FSN Analysis

Categorizing items according to their Issue/Use Frequency is a beneficial strategy for optimizing spare parts management. The designations F, S, and N are employed to represent items that move quickly, move slowly, and have a standard movement rate, respectively.

This classification approach streamlines the identification of regularly used items, those used infrequently, and items that haven't been used for an extended period. Employing this method allows for the creation of an efficient storage layout, positioning fast-moving items close to the dispensing window to minimize handling efforts.

Moreover, the management directs its attention towards non-moving items, making decisions regarding their ongoing necessity or potential salvage. Studies reveal that numerous industries, operating for more than 15 years, have more than half of their inventory comprised of non-moving spare parts. Even disposing of a few items can release tied-up capital, thereby generating extra working capital for the organization. Decisions regarding the disposal of spare items should be made considering the value of each item, and this process should be executed promptly and efficiently. (Potphode, 2018)

2.9 Multi-Criteria Analysis Decision Making

Molenaers et al. (2011) advocate the adoption of multicriteria analysis for creating a multi-criteria classification method based on the criticality of spare parts. Several factors influencing spare parts criticality are considered in this approach, including equipment criticality, the likelihood of item failure, replenishment duration, potential supplier quantity, accessibility of technical specifications, and the type of maintenance needed. These attributes are utilized to classify spare parts into four distinct criticality levels: high, medium, low, and none. The multi-criteria classification methodology is grounded in the Analytic Hierarchy Process (AHP), a widely utilized approach in maintenance and spare part management. AHP, a theory employing pairwise comparisons and expert judgments to establish priority scales (Saaty, 2008), has found application in diverse industries, such as the textile industry for maintenance policy selection (Ilangkumaran & Kumanan, 2009), aircraft spare parts inventory management (Nariswari et al., 2019), and general spare parts inventory management (Muniz et al., 2020). AHP has also been used in evaluating maintenance practices in TVET institutions (Njeru & Muchiri, 2022), criticality evaluation of spare parts (Ilgin, 2019), and criticality analysis of spare parts using a fuzzy AHP approach (Durán, 2015). Furthermore, AHP has been implemented in building maintenance procurement selection (Chua et al., 2015), multi-criteria assessment of spare parts of hydraulic systems (Torre & Salomon, 2022), and classification of critical spares for aircraft maintenance (Rad et al., 2011).

In the context of spare part management, AHP has been used for spare part supplier selection (Kusumah et al., 2021), dynamic supplier selection approach for a mining equipment company (Ahmad et al., 2019), and forecasting spare part demand using service maintenance information (Boute et al., 2019).

Furthermore, AHP has been employed in the context of spare parts inventory management, specifically in maintenance planning by Zhu et al. (2020), and in the auto spare parts industry by Zhang et al. (2020)

2.10 Most related topic

To gain a deeper understanding of the relationships and factors influencing spare parts criticality, involves a comprehensive review of literature, considering key elements such

as authorship, geographic context, industry or institution, research purpose, methodology, method analysis, and results as shown at Table 1.

Table 1. Related Topic Journal

No.	Author(s)	Year	Industry	Purposes of the research	Methodology	Analysis Method	Result and Conclusion
1	K. Antosz	2019	Manufacturing	- Develop an empirical model for criticality analysis - Perform spare part prioritization using analytic hierarchy process	MLDT (Mean Logistic Delay Time)	- Empirical model (EM) for criticality analysis - Analytic hierarchy process (AHP) for spare part prioritization	- Development of an empirical model for criticality analysis - Spare part prioritization using analytic hierarchy process
2	- B. Kareem - A. Lawal	2015	Automotive maintenance industry.	- Develop a system for dynamically determining critical equipment/spare parts. - Predict spare parts failure and provide remedy.	- Developed a system for spare part failure prediction - Used factors such as failure pattern, grouping, and failure probability	- Spare parts failure prediction model based on factors such as failure pattern, grouping, and failure probability. - Control characteristics of spare parts considered: criticality, specificity, and generality.	- Developed framework for spare part failure management - Used modified forecasting technique and ABC analysis
3	- Authors' names are not provided in the text.	2018	Energy	- Determine optimized spare part inventory for offshore wind farm substations - Lower risk level of critical components through spare parts procurement	- Algorithm based on failure mode and effects analysis - Linear optimization to reduce spare part inventory	Failure mode and effects analysis (FMEA) analysis method.	- Algorithm determines optimized spare part inventory - Risk-level of critical components significantly lowered
4	Sakon Wongmongkolrit, Bordin Rassameethes, and Kulnatee Laohakul	2016	Manufacture	- Find ratio between opportunity cost and spare parts inventory cost - Generate ratio as indication index for classification	- Ratio of production lost cost to spare parts inventory cost - Classification of criticality for spare parts	- Ratio of production lost cost to spare parts inventory cost - Indication index for classifying spare parts	- Ratio of production lost cost to inventory cost - Classification of spare parts based on criticality
5	- J Stoll, R Kopf, J Schneider, G Lanza - Á Kopf, Á Schneider, Á Lanza	2015	Warehouse Service	- Develop a multi-criteria criticality analysis for spare parts management - Identify rationalization potential in merging decentralized storage sites	- Three-dimensional classification approach for spare parts - Analytic hierarchy process used for multi-criteria decision making	- AHP (Analytic Hierarchy Process) is used for the VED analysis. - Decision tree is developed to solve multi-criteria decision problems.	- Classification approach developed for identifying suitable spare parts. - 15,000 out of 50,000 items suitable for central warehousing.
6	- Sarojini Jajimoggala - V Kesava	2012	Manufacture	- Evaluation of criticality of spare parts - Control of spare parts inventory systems	- Three phase hybrid model using fuzzy ANP and fuzzy TOPSIS - Eight-step procedure for evaluation and ranking of spare parts	Hybrid MCDM technique (ANP and TOPSIS) Eight-step procedure for criticality evaluation of spare parts	- A three-phase methodology is proposed for identifying critical spare alternatives. - The methodology uses fuzzy ANP and fuzzy TOPSIS for evaluation.
7	- An Molenaers - Herman Baets	2012	Petrochemical industry Asset-intensive industry	- Develop and implement a practical classification scheme - Bridge the gap between theory and practice	- Multi-criteria classification approach was developed and validated. - Microsoft Excel was used as the preferred program.	- Multi-criteria analysis used for spare part classification. - AHP used to solve multi-criteria decision sub-problems.	- Proposed multi-criteria classification method based on spare parts criticality - Classified spare parts into four classes based on criticality levels
8	- Authors: Not provided in the given information.	2008	Manufacture	- Establish spare parts criticality for unplanned maintenance - Rationalize efficiency of plant spare parts inventory	- Top-down Failure Modes Effects and Criticality Analysis (FMECA) - Introduction of Component Dynamic Criticality concept	- Top-down Failure Modes Effects and Criticality Analysis (FMECA) - Component Dynamic Criticality concept	- Methodology and DSS for spare parts criticality - Application example demonstrates the method
9	- Pao-Long Chang - Ying-Chyi Chou - Ming-Guang Huang	2005	Semiconductor Manufacture	- Develop an inventory model for spare parts - Handle critical and non-critical demand effectively	- (r,r,Q) inventory model for spare parts - Solution procedure to determine reorder point and quantity	SAS language Optimal solution obtained using the algorithm	- Model enables handling different classes of demand. - Relevant cost function is convex.
10	- Endah Budiningsih - Dan Wakhid - Ahmad Jauhari	2017	Garment production N/A	- Determine appropriate inventory control method for each group - Calculate safety stock, reorder point, and optimal ordering quantity	- ABC analysis method for spare parts grouping - Forecasting methods: Croston, SBA, SES	- Croston's method for lumpy demand forecasting - Syntetos-Boylan Approximation (SBA) method for forecasting	- 12 spare parts had the best forecasting method using Croston method - 6 spare parts had the best forecasting method using Syntetos-Boylan Approximation (SBA) method

Table.1 Related Topic Journal (continued)

No.	Author(s)	Year	Industry	Purposes of the research	Methodology	Analysis Method	Result and Conclusion
11	- Behzad Ghodrati - Uday Kumar	2005	Mining industry.	- Enhancing system availability by minimizing equipment downtime. - Determining the required number of spare parts.	- Model provided to determine required spare parts - Reliability and operating environment considered in model	Cox regression analysis with stepwise covariate selection.	- Lack of spare parts causes unexpected downtimes. - Operating environment affects system performance and reliability.
12	- Intan Dewi - Wakhid Jauhari	2018	Garment industry.	- Design inventory control for sewing machine spare parts - Determine critical spare parts and propose inventory model	- Study focuses on single needle sewing machine. - Spare parts categorized using ABC classification method.	- Hazard function approach - Continuous review policy based on Hadley Within Approach	- Optimal inventory policy achieved high service level. - Proposed method guarantees availability of spare parts.
13	- Anwar She&h - Frank Callom	1991	- Chemical and oil companies - Food processing industry	- Calculate spare part requirements for non-repairable systems - Develop purchasing strategies based on time between failures	- Methodology involves calculating spare part requirements for non-repairable systems. - Methodology includes stochastic characterization of time between failures.	- Stochastic characterization of time between failures - Historical usage rates for spare parts	- Methodology for calculating spare part requirements - Purchasing strategies based on time between failures
14	- Janne Huiskonen	2001	Paper manufacturing industry in Finland.	- Improve decision-maker's understanding of control requirements - Study effects of operational control characteristics on logistics system design	- Analyzing operational characteristics of spare parts - Considering product-specific characteristics in logistics system design	- Multiple criteria classification for spare part inventory management - General grouping method for defining operational control policies	- Advances in inventory research have not been easily implemented in managerial practice. - Qualitative approach used to increase understanding of problem situation.
15	- Authors: Not mentioned in the given information.	2018	N/A	- Present a framework for OR in spare parts management - Investigate the gap between theory and practice	- Framework for OR in spare parts management - Systematic literature review of OR in spare parts management	- Framework for OR in spare parts management - Systematic literature review of OR in spare parts management	- Framework for OR in spare parts management presented - Extended version of framework proposed, future research directions discussed
16	Mia Juliana Siregar	2021	Automotive sector.	- To determine the economical amount of product to be ordered - To establish the minimum and maximum stock quantity	- EOQ method used for ordering goods estimation - Min-Max Inventory method used for determining stock quantity	- EOQ (Economic Order Quantity) method - Min-Max Inventory method	- Economic order quantity (EOQ) is 386 pcs. - Company can save Rp3,939,330 per year.
17	Babatunde Omoniyi Odedairo	2021	Motorcycle assembly plant (MAP)	- Develop a spare parts inventory model - Incorporate ignored holding costs with a storage constraint	- Spare parts categorized using ABC analysis - Spare parts inventory model formulated and executed using Lingo optimization software	- Spare parts categorized using ABC analysis - Lingo optimization software used for model execution	- A spare parts inventory model was developed that incorporates holding costs and storage constraints. - The model resulted in a 67.9% reduction in total inventory cost.
18	Edgar Ramos, Timothy J. Pettit, Monika Flanagan, Luis Romero, Katherine Huayta	2020	Automotive sector.	- Managing cost-effective spare parts in automotive sector - Achieving best service level in automotive industry	- Case study on demand forecast of spare parts - Selection of best policies within each SKU category	- Case study on demand forecast and inventory control - Selection of best policies within each SKU category	- Reduction of stock rupture and savings in purchases - Increase of 22.49% in sales
19	C F Angelina, Fransiskus Tatas Dwi Atmaji, B Santosa	2020	Manufacturing company in medicines, food, and natural products.	- To identify the causes of machine delay - To determine optimal spare part inventory policy	- Reliability Centered Spare (RCS) method used - Poisson process and Min-Max stock analysis applied	Reliability Centered Spare (RCS) method Poisson process and Min-Max stock analysis	- RCS method used to calculate optimal spare part policy - Critical components for Rovema's machine identified
20	Valeriana Lukitosari, Apol Priyadi Subriadi, I Siyamah	2019	N/A	- Minimize costs - Reduce backorder risks	- Spare part inventory method based on customer priority - Lagrange multiplier method used to solve inventory model	Lagrange multiplier method used for inventory model.	- Customer priorities reduce costs and backorder risks. - Model verification conducted in real practice.

Table.1 Related Topic Journal (continued)

No.	Author(s)	Year	Industry	Purposes of the research	Methodology	Analysis Method	Result and Conclusion
21	Maliheh Vaez-Alaei, Nasim Zandi Atashbar, Armand Baboli, Romy Tonadre	2018	Business aircraft industry.	- Optimize business aircraft spare parts inventory system - Focus on cost effective inventory management and availability level	- Methodology proposed to optimize business aircraft spare parts inventory system - Heuristic method based on greedy algorithm proposed	- Methodology proposed to find optimal Target Stock Levels (TSL), Re-Order Point (ROP), Safety Stock (SS), and Expected Backorder (EBO) - Heuristic method based on greedy algorithm used for optimization	- Proposed methodology for optimizing spare parts inventory system - Best scenario is Poisson or Normal distributions for demand during lead-time
22	Rodrigo Pascual, Gabriel Santelices, Armin Lüer-Villagra, Jorge Vera, Alejandro Mac Cawley	2017	Asset intensive fields	- Optimize spare parts procurement policy - Increase asset availability and reduce procurement costs	- Optimization model for spare parts procurement - Heuristic procedure for fast and consistent solutions	- Optimization model for spare parts procurement - Heuristic procedure for fast and consistent solutions	- The optimization model maximizes equipment availability under TBVD. - The heuristic procedure improves the time required for solutions.
23	Thomas R. Klim, Monty L. Griffin	2006	N/A	- Determine optimal stocking levels for spare parts - Integrate parts demand planning with manufacturing processes	- Statistical analysis of historical demand values - Integration of parts demand planning with other systems	- Statistical analysis of historical demand values - Integration with engineering and facility maintenance systems	- Optimal stocking levels determined based on historical demand - Spare parts inventory management integrated with manufacturing processes
24	U. C. Moharana, Sarada Prasad Sarmah	2016	N/A	- Determine optimal stock levels for dependent spare parts - Incorporate dependency of items in inventory control policy	- Association rule technique used for finding dependency - Two item periodic review inventory policy developed	- Association rule technique for finding dependency among spare parts. - Computation of dependency factor using historical consumption records.	- Dependency among spare parts affects stock levels. - Stock levels can be reduced by considering dependency.
25	Hartanto Wong, Dirk Cattrysse, Dirk Van Oudheusden	2005	Airline industry.	- Determine spare parts stocking levels in a multi-hub system - Minimize total system cost in repairable inventory system	- Analytical model for determining spare parts stocking levels - Two-stage solution for optimal stocking levels	- Analytical model for determining spare parts stocking levels - Approximation method to compute logistical system performance measures	- Developed solution methodology for analyzing inventory pooling - Methodology closely approximates results obtained using queuing models
26	Haitao Liao, Peng Wang, Tongdan Jin, S. Repaka	2008	N/A	- Develop a spare parts management model - Minimize inventory cost under service level constraint	- Mathematical model formulated and calculated through simulation. - Dynamic (Q, r) restocking policy formulated and solved.	- Mathematical model formulated and calculated through simulation. - Dynamic (Q, r) restocking policy formulated and solved.	- Mathematical model and simulation for maintenance demand - Dynamic restocking policy to minimize inventory cost
27	Zheng Bingqing	2020	N/A	- Propose spare parts scheme based on probability distribution - Construct cost-oriented inventory model for spare parts	- Spare parts scheme based on probability distribution - Cost-oriented inventory model with random lead time	- Spare parts scheme based on probability distribution - Kolmogorov-Smirnov (K-S) goodness-of-fit test	- Proposed spare parts scheme based on probability distribution - Verified effectiveness of spare parts classification scheme
28	Ying-Chyi Chou, Pao-Long Chang, Ming-Guang Huang	2003	N/A	- Develop a model for spare parts inventory management - Demonstrate the implementation of the model in a semiconductor equipment company	- Model developed to evaluate inventory level and service level - Moving sum method used to estimate parameters	- Least squares method for failure rate estimation - Gamma distribution for approximating demand frequency data	- Traditional inventory control technique is inappropriate for slow-moving items. - Parts demand rate varies with machine's life cycle.
29	M. H. Kibria, M. M. A. Khan, A. B. M. A. Malek, P. K. Biswas	2020	Cement industries.	- Minimize inventory cost through categorization and demand forecasting. - Identify most valuable items and predict their demand.	- ABC analysis used for spare parts categorization - Croston's method used for demand forecasting	ABC analysis for identifying valuable items Croston's method for demand forecasting	- ABC analysis identified most valuable items. - Croston's method predicted demand and reduced inventory cost.
30	Endah Budiningsih, Wakhid Ahmad Jauhari	2017	Garment production N/A	- Determine appropriate inventory control method for spare parts - Forecast spare part demands using different methods	- ABC analysis method used for spare parts grouping - Croston, SBA, and SES used for demand forecasting	- Croston method for lumpy demand forecasting - Syntetos-Boylan Approximation (SBA) method for forecasting	- 12 spare parts had the best forecasting method using Croston method - 6 spare parts had the best forecasting method using Syntetos-Boylan Approximation (SBA) method
31	Babatunde Omoniyi Odedairo	2021	Motorcycle assembly plant (MAP)	- Develop a spare parts inventory model - Incorporate ignored holding costs with a storage constraint	- Spare parts categorized using ABC analysis - Spare parts inventory model formulated and executed using Lingo optimization software	- Spare parts categorized using ABC analysis - Lingo optimization software used for model execution	- A spare parts inventory model was developed that incorporates holding costs and storage constraints. - The model resulted in a 67.9% reduction in total inventory cost.
32	C F Angelina, Fransiskus Tatas Dwi Atmaji, B Santosa	2020	Manufacturing company in medicines, food, and natural products.	- To identify the causes of machine delay - To determine optimal spare part inventory policy	- Reliability Centered Spare (RCS) method used - Poisson process and Min-Max stock analysis applied	Reliability Centered Spare (RCS) method Poisson process and Min-Max stock analysis	- RCS method used to calculate optimal spare part policy - Critical components for Rovema's machine identified
33	Valeriana Lukitosari, Apol Priyadi Subriadi, I Siyamah	2019	Manufacturing	- Minimize costs - Reduce backorder risks	- Spare part inventory method based on customer priority - Lagrange multiplier method used to solve inventory model	Lagrange multiplier method used for inventory model.	- Customer priorities reduce costs and backorder risks. - Model verification conducted in real practice.

Table.1 Related Topic Journal (continued)

No.	Title	Author(s)	Year	Industry	Purposes of the research	Methodology	Analysis Method	Result and Conclusion
34	Target stock level and fill rate optimization for worldwide spare parts inventory management: A case study in business aircraft industry	Maliheh Vaez-Alaei, Nasim Zandi Atashbar, Armand Baboli, Romy Tonadre	2018	Business aircraft industry.	- Optimize business aircraft spare parts inventory system - Focus on cost effective inventory management and availability level	- Methodology proposed to optimize business aircraft spare parts inventory system - Heuristic method based on greedy algorithm proposed	- Methodology proposed to find optimal Target Stock Levels (TSL), Re-Order Point (ROP), Safety Stock (SS), and Expected Backorder (EOB) - Heuristic method based on greedy algorithm used for optimization	- Proposed methodology for optimizing spare parts inventory system - Best scenario is Poisson or Normal distributions for demand during lead-time
35	Optimal repairable spare-parts procurement policy under total business volume discount environment	Rodrigo Pascual, Gabriel Santelices, Armin L��r-Villagra, Jorge Vera, Alejandro Mac Cawley	2017	Asset intensive fields	- Optimize spare parts procurement policy - Increase asset availability and reduce procurement costs	- Optimization model for spare parts procurement - Heuristic procedure for fast and consistent solutions	- Optimization model for spare parts procurement - Heuristic procedure for fast and consistent solutions	- The optimization model maximizes equipment availability under TBVD. - The heuristic procedure improves the time required for solutions.
36	Spare parts inventory management	Thomas R. Klim, Monty L. Griffin	2006	Manufacturing	- Determine optimal stocking levels for spare parts - Integrate parts demand planning with manufacturing processes	- Statistical analysis of historical demand values - Integration of parts demand planning with other systems	- Statistical analysis of historical demand values - Integration with engineering and facility maintenance systems	- Optimal stocking levels determined based on historical demand - Spare parts inventory management integrated with manufacturing processes
37	Determination of optimal order-up to level quantities for dependent spare parts using data mining	U. C. Moharana, Sarada Prasad Sarmah	2016	Manufacturing	- Determine optimal stock levels for dependent spare parts - Incorporate dependency of items in inventory control policy	- Association rule technique used for finding dependency - Two item periodic review inventory policy developed	- Association rule technique for finding dependency among spare parts. - Computation of dependency factor using historical consumption records	- Dependency among spare parts affects stock levels. - Stock levels can be reduced by considering dependency
38	Classification and inventory control of spare parts based on compound Poisson Demand	Zheng Bingqing	2020	Manufacturing	- Propose spare parts scheme based on probability distribution - Construct cost-oriented inventory model for spare parts	- Spare parts scheme based on probability distribution - Cost-oriented inventory model with random lead time	- Spare parts scheme based on probability distribution - Kolmogorov-Smirnov (K-S) goodness-of-fit test	- Proposed spare parts scheme based on probability distribution - Verified effectiveness of spare parts classification scheme
39	An inventory model for slow moving spare parts of semiconductor equipment	Ying-Chyi Chou, Pao-Long Chang, Ming-Guang Huang	2003	Manufacturing	- Develop a model for spare parts inventory management - Demonstrate the implementation of the model in a semiconductor equipment company	- Model developed to evaluate inventory level and service level - Moving sum method used to estimate parameters	- Least squares method for failure rate estimation - Gamma distribution for approximating demand frequency data	- Traditional inventory control technique is inappropriate for slow-moving items. - Parts demand rate varies with machine's life cycle.
41	Analisis Pengendalian Persediaan Spare Part Mesin Produksi di PT. Prima Sejahtera dengan Metode Continuous Review	Endah Budiningsih, Wakhid Ahmad Jauhari	2017	Garment production	- Determine appropriate inventory control method for spare parts - Forecast spare part demands using different methods	- ABC analysis method used for spare parts grouping - Croston, SBA, and SES used for demand forecasting	- Croston method for lumpy demand forecasting - Syntetos-Boylan Approximation (SBA) method for forecasting	- 12 spare parts had the best forecasting method using Croston method - 6 spare parts had the best forecasting method using Syntetos-Boylan Approximation (SBA) method
42	Pengendalian Stok Spareparts Mobil Dengan Metode EOQ dan Min-Max Inventory	Mia Juliana Siregar	2021	Manufacturing	- To determine the economical amount of product to be ordered - To establish the minimum and maximum stock quantity	- EOQ method used for ordering goods estimation - Min-Max Inventory method used for determining stock quantity	- EOQ (Economic Order Quantity) method - Min-Max Inventory method	- Economic order quantity (EOQ) is 386 pcs. - Company can save Rp3,993,330 per year.

The summarized results provided in the table depict various studies and approaches related to spare parts management, inventory control, and criticality analysis across different industries and contexts. Here are some common themes and relations among the summarized results:

Methodologies and Techniques: Many of the studies propose or utilize specific methodologies and techniques for spare parts management, such as:

1. ABC Analysis, A method for categorizing items based on their importance.
2. Empirical Models (EM), these models are developed based on observed data rather than theoretical considerations.

3. Analytic Hierarchy Process (AHP), a method for decision-making that involves structuring a complex problem into a hierarchy of criteria and alternatives.
4. Failure Mode and Effects Analysis (FMEA), a systematic method for evaluating potential failure modes of components and their effects.
5. Inventory Models (e.g., EOQ), models used to determine optimal inventory levels and reorder points.
6. Data Mining Techniques, used for identifying patterns and dependencies among spare parts.
7. Hybrid Decision-Making Techniques, combining multiple methods like ANP and TOPSIS for decision-making.
8. Statistical Forecasting Methods, including Croston's method, Poisson process, and renewal process methods.
9. Optimization Models, used to optimize spare parts procurement, inventory levels, and system performance.
10. Hazard Function Approach, incorporates hazard functions to control spare part inventory.
11. Industry Application, the studies cover a wide range of industries including manufacturing, automotive, energy, petrochemical, semiconductor, garment production, paper manufacturing, mining, and more. Each industry may have unique requirements and challenges related to spare parts management.

The objectives of the studies vary but generally focus on improving system availability, reliability, and efficiency through better spare parts management. This includes minimizing downtime, reducing inventory costs, optimizing stocking levels, and ensuring critical spare parts availability. Many studies propose methods for criticality analysis, spare part prioritization, and decision support systems to aid in spare parts management. Some studies include case studies or practical validations to demonstrate the effectiveness of proposed methodologies in real-world scenarios. Overall, the relations among the most related topics is results highlight the diversity of approaches and techniques used in spare parts management and inventory control, with the common goal of enhancing system performance and reliability while minimizing costs and downtime.