Increasing Efficiency in Spare Parts Management: A Case Study of B.T. MINING Co., Ltd.

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Received: Mar 18, 2025; **Revised:** May 19, 2025; **Accepted:** Jun 06, 2025

Abstract

The research aims to enhance the efficiency of spare parts inventory management through the implementation of systematic classification and forecasting techniques. B.T. Mining Co., Ltd. seeks to minimize storage costs, optimize spare parts distribution, and mitigate the risk of shortages. The study began with data collection from the company's maintenance department, focusing on repair records, reimbursements, and storage costs over the past six years, from January 2018 to December 2023. According to the survey, the total spare parts value was 1,381,544.41 baht, prompting the researcher to explore and optimize inventory management. To achieve the research objective, ABC analysis was conducted to classify spare parts based on their utility value. Group A contained nine application values, Group B comprised 13 application values, and Group C included 21 application values. Further classification was applied to Group A, dividing it into two subgroups: parts with a coefficient of variation below 0.25, which were managed by using EOQ model, and parts with a coefficient of variation at least 0.25, which were analyzed along with certain spare parts from Group B. Following the implementation of the optimized inventory management strategy, the total inventory cost was reduced by 43,459.39 baht per year, representing a 56.76% decrease. Previously, excessive procurement of certain spare parts was used as a preventive measure against shortages, leading to high storage costs. The improved inventory management approach successfully addressed this issue, resulting in more efficient and cost-effective operations.

Keywords: Inventory Management, ABC Analysis, Cost, Forecasting

1. Introduction

B.T. Mining Co., Ltd., located at No. 599/7, Mae Mau Sub-district, Mae Moh District, Lampang Province 52220, is a contractor responsible for drilling holes to place explosives for excavation purposes. The company operates blast hole drilling machines that utilize lignite coal as fuel for electricity generation at Mae Mau Power Plant in Lampang Province and distributes electricity to other provinces. The General Administration department is responsible for managing the spare parts inventory recording between breakdown reports for drills, and maintaining accounting documents such as receipts, as shown in **Figure 1**.

The primary issue in the company's maintenance department is inefficient storage and distribution of spare parts due to a lack of systematic inventory management, leading to increased costs and operational delays. For example, unnecessary or broken spare parts occupy valuable storage space, causing inefficiencies. Additionally, excessive stocking of spare parts can lead to deterioration before use, while frequently required spare parts with a history of breakdowns and replacements are often not restocked. As a result, when an excavator requires maintenance according to its service cycle, the necessary spare parts may not be readily available, delaying repairs. In such cases, emergency orders must be placed, which can take between 3 to 5 months for delivery, and in extreme cases, up to a year. These delays render the drilling inoperable, disrupting production, and causing financial losses for the company.

Figure 1 Automatic Drilling Rig (Atlas COPCP 30II)
Source: B.T. Mining Co., Ltd.

The evident research gap arising from the described situation is the lack of an efficient and systematic spare parts inventory management system within the company's maintenance department. While the consequences of this issue (increased costs, operational delays) have been identified, there is a lack of in-depth research addressing:

- Root Causes of the Problem: What underlying factors contribute to the inefficient spare parts inventory management? (e.g., lack of software, unclear work processes, inaccurate spare parts demand forecasting, poor inter-departmental communication).
- Quantifiable Impacts: What is the actual monetary value of the increased costs and economic losses resulting from maintenance delays?
- Potential Solutions: What methods or technologies can be applied to improve spare parts inventory management efficiency? (e.g., ERP systems, automated warehouse management systems, advanced demand forecasting techniques).
- Evaluation of Solution Effectiveness: How can the outcomes and effectiveness of implemented solutions be measured and evaluated?

The research can focus on either a detailed exploration and analysis of the causes behind inefficient spare parts inventory management within this specific company or the presentation and evaluation of potential solutions to address these knowledge gaps. Importance of the Study:

- Reduce operational costs: Efficient spare parts inventory management will help lower unnecessary expenses such as costs for storing unused parts, depreciation of long-held inventory, and emergency order expenses.
- Minimize operational delays: Having necessary spare parts readily available will expedite maintenance, reduce machine downtime, and maintain continuous production.
- Enhance maintenance department efficiency: A well-managed spare parts inventory system will streamline the work of maintenance personnel, reduce confusion, and improve operational agility.
- Prevent financial losses: Reducing production delays and unnecessary costs will directly impact the company's profitability.
- Serve as a guideline for other companies: The study's findings and proposed solutions from this company may be beneficial and applicable to other companies facing similar challenges.

2. Related Theories and Research

The literature review highlights the essential role of advanced inventory management tools, including ABC analysis, the Variability Coefficient (VC), forecasting methodologies, Economic Order Quantity (EOQ), and Fixed Order Quantity (FOQ), in enhancing supply chain efficiency and responsiveness. ABC analysis is recognized as a fundamental approach to inventory categorization, enabling managers to prioritize high-value items, which is vital for optimizing resource allocation as discussed in studies [1] and [2]. Furthermore, the incorporating VC enhances the understanding of demand variability, enabling organizations to refine their inventory strategies, mitigating risks with shortages and surplus stock noted in [3].

Forecasting is highlighted as a pivotal methodology that strengthens inventory management by enabling accurate predictions of demand trends, aligning supply with market needs, and enhancing operational efficiency, as supported by findings in [4] and [5]. The EOQ and FOQ models contribute to cost-effective ordering strategies, helping balance holding costs with service levels, thus reinforcing their importance in inventory management literature [6] and [7]. Collectively, these methodologies affirm the necessity of adopting a holistic approach to inventory management, where their synergies enhance decision-making, streamline operations, and effectively respond to market complexities, a sentiment reiterated throughout the literature [8], [9], and [10].

Despite the effectiveness of these tools, limitation persist in existing research. A key gap remains in integrating these methodologies into a comprehensive framework that is applicable across diverse industry contexts, as identified in [11] and [12]. Moreover, the role of emerging technologies, such as artificial intelligence and the Internet of Things, in conjunction with traditional inventory management practices remains underexplored, presenting opportunities for future research [13] and [14].

3. Data Analytics Plan

The inventory management technique used in this research prioritizes spare parts through ABC analysis. Once classified, spare parts in Group A undergo further analysis to determine their Variability Coefficient (VC). Based on the VC value, they are categorized into two conditions:

- Condition 1: if the VC is less than 0.25, the forecasting technique is applied followed by the EOQ model, and FOQ.
- Condition 2: If the VC is 0.25 or higher, FOQ is directly applied. Additionally, certain spare parts in Group B also require management using the FOQ.

This classification ensures that appropriate inventory control methods are applied based on the variability of demand, optimizing both cost and efficiency as shown in **Figure 2.**

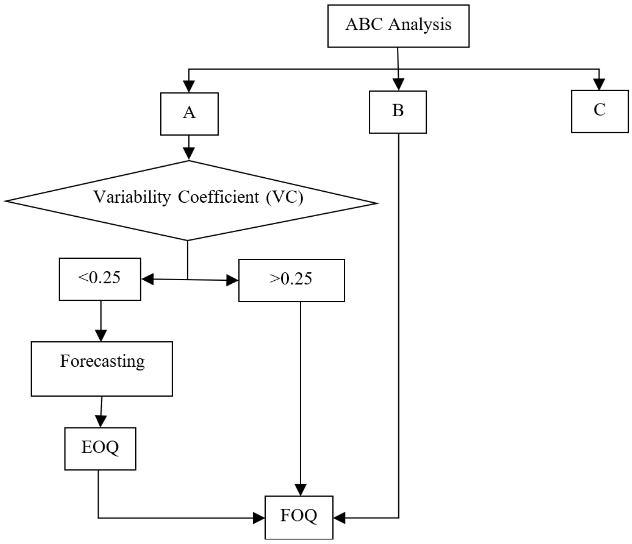

Figure 2 Data Analysis

Statistical forecasting is employed, and the significance of demand variability (often measured by the Coefficient of Variation, or CV) is typically discussed in the context of selecting the appropriate forecasting model and achieving forecasting accuracy. Industry best practices that utilize experience-based criteria for assessing forecasting difficulty may also be referenced [15].

3.1 Application of ABC Analysis Technique

3.1.1 Data for Analysis

The data required for analyzing spare parts inventory management, from January 2018 to December 2023, spanning 6 years, with data details as shown in **Table 1**.

Table 1 Data necessary for spare parts inventory management analysis.

No.	PART NO. (PART BOOK)	Spare Part	Lead Time	Reserve	Order quantity	Average demand times/year	Price/Unit
1	2310079523	Final drive	2	4	4	2.00	182,000.00
2	2310116880	Drag bit	1	4	5	45.00	8,000.00
3	2652146784	Rotary head (SET)	11	0	2	0.83	125,024.00
4	2310106599	Hydraulic oil cooler	2	1	1	0.67	153,000.00
5	2310037216	Air hose	3	1	1	2.50	39,500.00
6	2310116880	Bit sub	90	0	2	4.17	19,500.00
7	2310116880	Drill pipe	7	2	2	1.17	64,500.00
8	2310035251	Track roller 320	2	5	8	10.00	3,800.00
9	2657325649	Cartridge at hydraulic pump	2	0	2	0.67	39,042.00
10	2310035434	Front idler 320	1	0	2	2.00	12,800.00
11	2310116880	Top sub	90	0	2	1.33	18,000.00
12	2310035244	Sprocket	90	2	4	1.17	19,800.00
13	2658143348	Wire rope	7	2	2	5.83	2,250.00
14	2310049310	Dust filter	7	0	4	4.00	2,900.00
15	2310035269	Carrier	1	1	2	1.67	4,205.61
16	2310035277	Chain link + pin	1	2	2	2.83	1,770.00
17	2310049336	Dust hose	7	1	1	0.17	18,264.00
18	2657368524	Drive shaft	1	2	2	1.33	1,300.00
19	2310074862	Air Throttle Cylinder (SET2)	11	0	1	1.33	1,145.00
20	2310088623	Gear box (SET)	11	1	8	1.17	1,295.00
21	2310105567	Undercarriage System (SET)	7	0	2	1.33	980.00
22	2310075653	Mast cylinder (SET3)	2	1	4	0.67	1,834.00
23	C40K	Track roller	1	0	2	0.17	7,009.35
24	2310008696	Pin feed roller (T)	1	4	2	0.83	1,350.00

Table 1 Data necessary for spare parts inventory management analysis. (cont.)

No.	PART NO. (PART BOOK)	Spare Part	Lead Time	Reserve	Order quantity	Average demand times/year	Price/Unit
25	1625006850	Compressor Blowdown valve (SET)	7	0	2	1.17	855.00
26	2310099158	Guide of rotation head 10.4	11	0	16	2.17	450.00
28	2310075398	Lock cylinder (SET)	1	1	2	1.00	923.00
29	2310074953	Air Throttle Cylinder (SET1)	11	0	1	1.17	680.00
30	2310075968	Rod support cylinder (SET)	1	1	2	1.00	788.00
31	2310075653	Mast cylinder (SET4)	2	1	4	0.67	1,172.00
32	2310103570	Feed roller	11	4	4	0.83	800.00
33	2310007030	Pin feed roller (L)	11	10	4	0.83	800.00
34	2310076198	Bushing at tower	11	0	4	0.33	1,500.00
35	2310033843	Alternator belt	1	4	2	1.17	360.00
36	2657451924	Air compressor belt	1	0	2	2.67	140.00
37	2310075653	Mast cylinder (SET2)	2	1	4	0.67	441.00
38	2635849116	Piston at water pump	1	0	6	2.17	125.00
39	2310099158	Nut of guide Box	11	0	48	2.17	85.00
40	2310099158	Nut of guide slide	11	0	32	2.17	85.00
41	2310075653	Mast cylinder (SET1)	2	1	4	0.67	170.00
42	2310099315	Shim plate of rotation head 10.4	11	0	48	2.17	20.00
43	2310099323	Shim plate of rotation head 4	11	0	48	2.17	20.00

Calculation of Average Orders: Based on the collected data, the number of orders placed each year from 2018 to 2023 is as follows: 2, 2, 3, 1, 3, and 1 time, respectively. The average order frequency over this 6-year period is 2.0 time per year calculated as follows Eq. (1):

$$\text{Average Order} = \frac{\text{Total Number of Orders}}{\text{Number of years}} \tag{1}$$

3.1.2 Usage Value

The average order frequency of 2.0 times per year from Eq. (1) is multiplied with the usage value of each spare part to find the Usage Value as Eq. (2):

$$\text{Usage Value} = \text{Average Order} \times \text{Usage value of Spare Parts} \tag{2}$$

Example results for the calculation of the average order and Usage value for spare parts (Final Drive) are shown in **Table 2**.

Table 2 Calculation results of spare parts Utility value

NO.	PART NO. (PART BOOK)	Spare Parts	Usage Value
1	2310079523	Final drive	364,000.00
2	2310116880	Drag bit	360,000.00
3	2652146784	Rotary head (SET)	104,186.67
4	2310106599	Hydraulic oil cooler	102,000.00
5	2310037216	Air hose	98,750.00
6	2310116880	Bit sub	81,250.00
7	2310116880	Drill pipe	75,250.00
8	2310035251	Track roller 320	38,000.00
9	2657325649	Cartridge at hydraulic pump	26,028.00
10	2310035434	Front idler 320	25,600.00
11	2310116880	Top sub	24,000.00
12	2310035244	Sprocket	23,100.00
13	2658143348	Wire rope	13,125.00
14	2310049310	Dust filter	11,600.00
15	2310035269	Carrier	7,009.35
16	2310035277	Chain link + pin	5,015.00
17	2310049336	Dust hose	3,044.00

Table 2 Calculation results of spare parts Utility value (cont.)

NO.	PART NO. (PART BOOK)	Spare Parts	Usage Value
18	2657368524	Drive shaft	1,733.33
19	2310074862	Air Throttle Cylinder (SET2)	1,526.67
20	2310088623	Gear box (SET)	1,510.83
21	2310105567	Undercarriage System (SET)	1,306.67
22	2310075653	Mast cylinder (SET3)	1,222.67
23	C40K	Track roller	1,168.23
24	2310008696	Pin feed roller (T)	1,125.00
25	1625006850	Compressor Blowdown valve (SET)	997.50
26	2310099158	Guide of rotation head 10.4	975.00
27	2310099158	Guide of rotation head 4	975.00
28	2310075398	Lock cylinder (SET)	923.00
29	2310074953	Air Throttle Cylinder (SET1)	793.33
30	2310075968	Rod support cylinder (SET)	788.00
31	2310075653	Mast cylinder (SET4)	781.33
32	2310103570	Feed roller	666.67
33	2310007030	Pin feed roller (L)	666.67
34	2310076198	Bushing at tower	500.00
35	2310033843	Alternator belt	420.00
36	2657451924	Air compressor belt	373.33
37	2310075653	Mast cylinder (SET2)	294.00
38	2635849116	Piston at water pump	270.83
39	2310099158	Nut of guide Box	184.17
40	2310099158	Nut of guide slide	184.17
41	2310075653	Mast cylinder (SET1)	113.33
42	2310099315	Shim plate of rotation head 10.4	43.33
43	2310099323	Shim plate of rotation head 4	43.33
Total			1,381,544.41

3.1.3 Usage Value Percentage

The usage value percentage is calculated by dividing the total useful value of all spare parts by the total usage value of the spare parts, then multiplying by 100 as Eq. (3):

$$\% \text{ Usage Value} = \frac{\text{Usage Value} \times 100\%}{\text{Total Useful Value}} \quad (3)$$

3.1.4 Cumulative Usage Value Percentage

The cumulative usage value percentage is determined by summing the usage value percentage of each consecutive spare part as Eq. (4). For example, the Final Drive and Drag Bit parts have individual usage value percentages of 26.35% and 26.06%, respectively:

$$\%\text{Cumulative Usage Value} = \sum \%\text{Usage Value of each consecutive spare part} \quad (4)$$

3.1.5 Percentage of Cumulative Number of Spare Parts Items

The percentage of accumulated spare parts in Eq. (5) is calculated by multiplying the part's order in the list by 100 and dividing by the total number of spare parts. For example, the Final Drive spare parts is the first in the order out of 43 spare parts:

$$\%\text{Cumulative number of spare parts items} = \frac{\text{Accumulated Spare Parts} \times 100\%}{\text{Total Number of Spare Parts}} \quad (5)$$

3.1.6 Prioritization of Spare Parts:

The prioritization of spare parts using the ABC analysis technique is determined by comparing the cumulative usage value percentage with the cumulative percentage of spare parts. The classification results are detailed in **Table 3** and summarized in **Table 4** and **Figure 3**.

Table 3 Spare parts prioritization: Groups A, B and C

NO.	Spare Part	Value Active	%Usage Value	%Cumulative Usage Value	%Cumulative number of spare parts items
Group A					
1	Final drive	364,000.00	26.35	26.35	2.33
2	Drag bit	360,000.00	26.06	52.41	4.65
3	Rotary head (SET)	104,186.67	7.54	59.95	6.98
4	Hydraulic oil cooler	102,000.00	7.38	67.33	9.30

Table 3 Spare parts prioritization: Groups A, B and C (cont.)

NO.	Spare Part	Value Active	%Usage Value	%Cumulative Usage Value	%Cumulative number of spare parts items
5	Air hose	98,750.00	7.15	74.48	11.63
6	Bit sub	81,250.00	5.88	80.36	13.95
7	Drill pipe	75,250.00	5.45	85.81	16.28
8	Track roller 320	38,000.00	2.75	88.56	18.60
9	Cartridge at hydraulic pump	26,028.00	1.88	90.44	20.93
Group B					
1	Front idler 320	25,600.00	1.85	92.29	23.26
2	Top sub	24,000.00	1.74	94.03	25.58
3	Sprocket	23,100.00	1.67	95.70	27.91
4	Wire rope	13,125.00	0.95	96.65	30.23
5	Dust filter	11,600.00	0.84	97.49	32.56
6	Carrier	7,009.35	0.51	98.00	34.88
7	Chain link + pin	5,015.00	0.36	98.36	37.21
8	Dust hose	3,044.00	0.22	98.58	39.53
9	Drive shaft	1,733.33	0.13	98.71	41.86
10	Air Throttle Cylinder (SET2)	1,526.67	0.11	98.82	44.19
11	Gear box (SET)	1,510.83	0.11	98.93	46.51
12	Undercarriage System (SET)	1,306.67	0.09	99.02	48.84
13	Mast cylinder (SET3)	1,222.67	0.09	99.11	51.16
Group C					
1	Track roller	1,168.23	0.08	99.20	53.49
2	Pin feed roller (T)	1,125.00	0.08	99.28	55.81
3	Compressor Blowdown valve (SET)	997.50	0.07	99.35	58.14
4	Guide of rotation head 10.4	975.00	0.07	99.42	60.47
5	Guide of rotation head 4	975.00	0.07	99.49	62.79
6	Lock cylinder (SET)	923.00	0.07	99.56	65.12
7	Air Throttle Cylinder (SET1)	793.33	0.06	99.61	67.44
8	Rod support cylinder (SET)	788.00	0.06	99.67	69.77
9	Mast cylinder (SET4)	781.33	0.06	99.73	72.09
10	Feed roller	666.67	0.05	99.78	74.42
11	Pin feed roller (L)	666.67	0.05	99.82	76.74
12	Bushing at tower	500.00	0.04	99.86	79.07
13	Alternator belt	420.00	0.03	99.89	81.40
14	Air compressor belt	373.33	0.03	99.92	83.72
15	Mast cylinder (SET2)	294.00	0.02	99.94	86.05
16	Piston at water pump	270.83	0.02	99.96	88.37
17	Nut of guide Box	184.17	0.01	99.97	90.70
18	Nut of guide slide	184.17	0.01	99.99	93.02
19	Mast cylinder (SET1)	113.33	0.01	99.99	95.35
20	Shim plate of rotation head 10.4	43.33	0.003	100.00	97.67
21	Shim plate of rotation head 4	43.33	0.003	100.00	100.00

Many spare parts in categories B and C have very low usage volumes. For example

- Dust hose (3,044 Baht) is used only 1 unit per year.
- Guide of rotation head (975 Baht) is used 1 unit per year.
- Mast cylinder (294 – 781 Baht) is used less than 1 unit per year.

Table 4 Summary of ABC prioritization

Group	Number of spare parts	%Number of Parts Items	%Usage Value	Usage Value (Bath)
A	9	20.93	90.44	1,249,464.67
B	13	30.23	8.67	119,793.52
C	21	48.84	0.89	12,286.23
Total	43	100	100	1,381,544.41

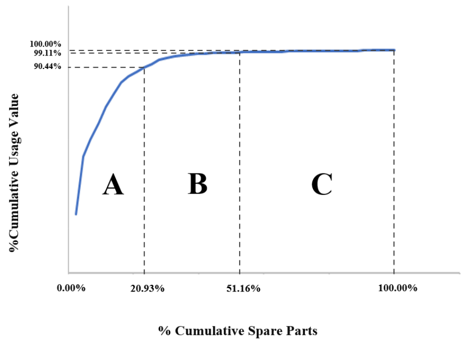

Figure 3 Graph of the company's ABC spare parts prioritization ratio.

From **Table 4** and **Figure 3**, the results of the ABC analysis for spare parts prioritization indicate the following:

- Group A consists of 9 spare parts, accounting for 20.93% of the total spare parts list and representing 90.44% of the total spare parts usage value.
- Group B includes 13 spare parts, making up 30.23% of the total spare parts list and 8.67% of the total spare parts usage value.
- Group C contains 21 spare parts, accounting for 48.84% of the total spare parts list and 0.89% of the total spare parts usage value.

From **Table 5** Drag Bits show high and continuous demand. The Winters' Method proved to be the ** most accurate forecasting technique** for demand, yielding the lowest MAPE at 1.09%. EOQ (Economic Order Quantity) was utilized to calculate the optimal order quantity.

Table 5 High-Demand Parts

Spare Parts	Units per year	Total Value (Bath)
Drag Bit	45	360,000
Bit Sub	5	81,250
Track Roller 320	10	38,000

From **Table 6** Low VC (Group 1): Indicates stable demand, highly effective forecasting, and efficient order quantity control using EOQ. High VC (Group 2): Indicates highly volatile demand, potentially higher forecasting errors, and the necessity of Safety Stock to manage uncertainty, maintain service levels, and prevent process disruptions.

Table 6 Coefficient of Variation (VC)

Group	Criterion	Quantity of Spare Parts	Technic
Group 1	VC < 0.25	6	EOQ + Forecasting
Group 2	VC ≥ 0.25 or Group B	16	FOQ + Safety Stock

From **Figure 4–5** Drag Bits are our most in-demand spare part, both in terms of quantity (45 units per year) and value (360,000 Baht/year). While Bit Subs and Track Roller 320s have lower demand, they are still considered high-demand items compared to other spare parts on the list.

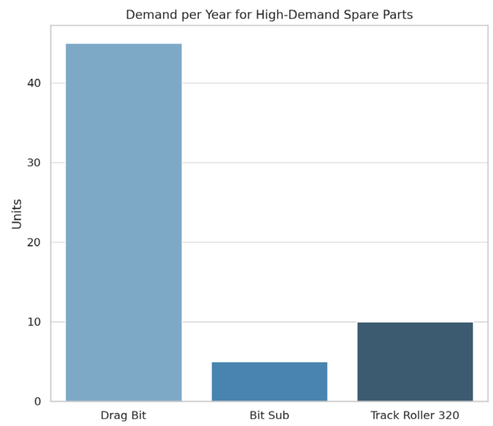

Figure 4 Demand per year for high-demand spare parts

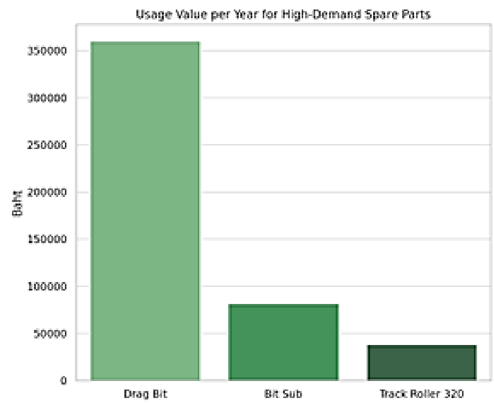

Figure 5 Usage value per year for high-demand spare parts

3.2 Variability Coefficient

Based on the prioritization of spare parts using the ABC Analysis technique, the researcher selected Group A spare parts, which have the highest usage value and importance. This group consists of 9 items used to calculate the VC. The VC is obtained by dividing the variance of demand (Est.varD) by the square of the average order. The demand variance (Est.varD) is calculated by using Eq. (6) as 0.67.

$$\text{Est.varD} = \frac{\sum (d_i^2 - \bar{d}^2)}{n} \tag{6}$$

Once the variance of demand (Est.varD) is determined, the VC equals 0.17 that can be calculated as follows in Eq. (7):

$$\text{VC} = \frac{\text{Est.varD}}{\bar{d}^2} \tag{7}$$

Based on the calculated VC for group A spare parts, the researcher identified two conditions for inventory management:

Condition1 or Spare Parts Group 1: Spare parts of Group 1 have VC less than 0.25, indicating a stable and predictable demand pattern. These parts are suitable for the EOQ technique to optimize ordering and reduce costs. **Table 7** and **Figure 4** illustrate the list of spare parts in Group 1, which consists of 6 out of 9 items in Group A that qualify for EOQ-based analysis.

Table 7 Spare parts in Group 1

NO.	PART NO. (PART BOOK)	Spare Parts	Est. varD
1	2310079523	Final drive	0.67
2	2310116880	Drag bit	16.67
3	2652146784	Rotary head (SET)	0.14
4	2310037216	Air hose	1.25
5	2310116880	Bit sub	0.47
6	2310035251	Track roller 320	4.33

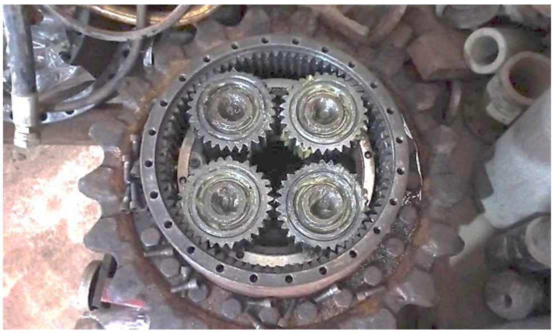

Figure 6 Final drive (Spare Parts)
Source: B.T. Mining Co., Ltd.

3.2.1 Condition 2 or Spare Parts Group 2

Spare parts in Group 2 have VC greater than 0.25, indicating irregular demand. These parts are suitable for the FOQ due to their unpredictable demand. The researcher also included Group B spare parts in the analysis since Group B parts have medium importance and should also be reserved. **Table 8** and **Figure 7** show the Group 2 spare parts, which include:

- 3 items from Group A with a VC greater than 0.25
- 13 items from Group B totaling 16 items.

Table 8 Spare parts in Group 2

NO.	Spare Parts	Est. varD	VC	Group
1	Hydraulic oil cooler	1.22	2.75	A
2	Drill pipe	0.47	0.35	A
3	Cartridge at hydraulic pump	1.22	2.75	A
4	Front idler 320	-	-	B
5	Top sub	-	-	B
6	Sprocket	-	-	B
7	Wire rope	-	-	B

Table 8 Spare parts in Group 2 (cont.)

NO.	Spare Parts	Est. varD	VC	Group
8	Dust filter	-	-	B
9	Carrier	-	-	B
10	Chain link + pin	-	-	B
1	Dust hose	-	-	B
12	Drive shaft	-	-	B
13	Air Throttle Cylinder (SET2)	-	-	B
14	Gear box (SET)	-	-	B
15	Undercarriage System (SET)	-	-	B
16	Mast cylinder (SET3)	-	-	B

Note: The VC does not need to be calculated for Group B since FOQ is used for both static and irregular demand patterns.

Figure 7 Top sub (Spare Parts)
Source: B.T. Mining Co., Ltd.

3.3 Forecasting

The spare parts in Group 1 (VC < 0.25) are used for forecasting demand for the next year (2024). This group consists of six spare parts, namely: Final Drive, Rotary Head (SET), Air Hose, Bit Sub, Track Roller 320 and Drag Bit respectively

3.3.1 Moving Average Forecasting

The moving average (MA) Length is set to 3 because the lowest MAPE, MAD, and MSD values. An example of Final Drive Parts List forecasting is illustrated in **Figure 8**.

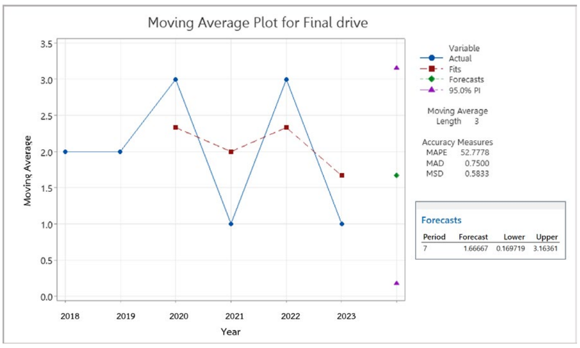

Figure 8 Forecasting by Moving Average of Final Drive Parts List

The forecast value for Final Drive spare parts using MA is 1.66667. The forecast error evaluation indices as MAPE, MAD and MSD are 52.7778, 0.7500 and 0.5833, respectively. **Table 9** summarizes the forecast value for Group1 spare parts.

Table 9 Moving Average forecasting for Group 1

Moving Average				
Spare Parts	**Forecast for 2024**	**MAPE**	**MAD**	**MSD**
Final drive	2	52.7778	0.7500	0.5833
Rotaryhead (SET)	1	8.3333	0.0833	0.0278
Air hose	1	31.2500	0.9167	1.0278
Bit sub	5	12.9167	0.5833	0.4167
Track roller 320	10	15.7804	1.6667	4.8333
Drag bit	45	8.3318	3.5833	20.25

3.3.2 Exponential Smoothing Forecasting

The smoothing constant (α) is set to 0.01 to minimize MAPE, MAD, and MSD values. For example, the forecast of the Final Drive spare parts list is shown in **Figure 9**.

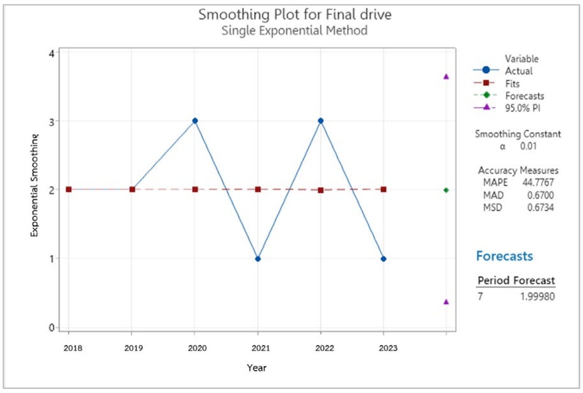

Figure 9 Exponential Smoothing Forecast of Final Drive Parts

The Exponential Smoothing for Final Drive Parts Lists 1.99980 and the forecast error evaluation indices as MAPE, MAD and MSD are 44.7767, 0.6700 and 0.6734, respectively as shown in **Table 10**.

Table 10 Exponential Smoothing Forcast for Group 1 Spare parts

Exponential Smoothing				
Spare Parts	**Forecast for 2024**	**MAPE**	**MAD**	**MSD**
Final drive	2	44.7767	0.6700	0.6734
Rotaryhead (SET)	1	17.1535	0.2818	0.1403
Air hose	3	50.0047	1.0025	1.2625
Bit sub	4	14.1348	0.5569	0.4769
Track roller 320	10	13.7811	1.3384	4.3768
Drag bit	45	6.0668	2.6699	16.8336

3.3.3 Winters' Method Forecasting

The multiplicative Holt-Winters model is particularly well-suited for time series data where the amplitude of seasonal fluctuations is not constant. [17] The model parameters are configured as α (level) = 1, γ (trend) = 1, and δ (seasonal) =1 to minimize MAPE, MAD, and MSD. An example of the forecast of the final drive spare parts list is shown in **Figure 10**.

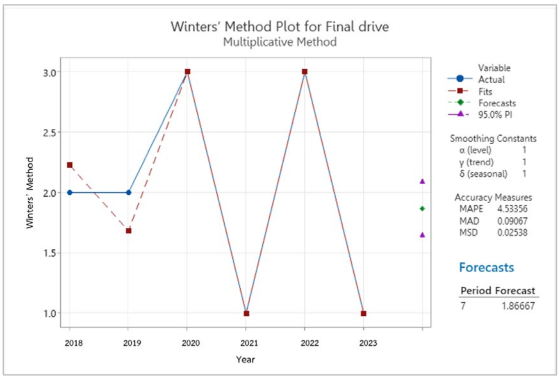

Figure 10 Winters' Method Forecast of Final Drive Parts List

The Winters' Method forecast for Final Drive Parts List is 1.86667 and the MAPE, MAD and MSD are 4.5336, 0.0907 and 0.0254, respectively. The results of the Winters' Method are shown in **Table 11.**

Table 11 Winter's Method Forecast for Group 1 Spare Parts

Winters' Method					
PART NO. (PART BOOK)	**Spare Parts**	**Forecast for 2024**	**MAPE**	**MAD**	**MSD**
23100 79523	Final drive	2	4.5336	0.0907	0.0254
26521 46784	Rotaryhead (SET)	1	12.6872	0.0787	0.0325
23100 37216	Air hose	1	8.5811	0.1356	0.0673
23101 16880	Bit sub	4	3.6357	0.1243	0.0464
23100 35251	Track roller 320	10	2.2229	0.2223	0.1523
23101 16880	Drag bit	44	1.0991	0.4946	0.7546

3.3.4 Forecasting Model Selection

The best forecasting model is selected based on the lowest MAPE, MAD and MSD values as shown in **Table 12**. This means that the forecast model has minimum error. Hence, the Winters' method is the optimal forecasting technique.

Table 12 Results of selecting the right forecast model for the spare parts list

PART NO. (PART BOOK)	Spare Parts	MAPE			MAD			MSD		
		Moving Average	Exponential Smoothing	Winters' Method	Moving Average	Exponential Smoothing	Winters' Method	Moving Average	Exponential Smoothing	Winters' Method
23100 79523	final drive	52.7778	44.7767	**4.5336**	0.7500	0.6700	**0.0907**	0.5833	0.6734	**0.0254**
26521 46784	rotary head (SET)	**8.3333**	17.1535	12.6872	0.0833	0.2818	**0.0787**	**0.0278**	0.1403	0.0325
23100 37216	air hose	31.2500	50.0047	**8.5811**	0.9167	1.0025	**0.1356**	1.0278	1.2625	**0.0673**
23101 16880	bit sub	12.9167	14.1348	**3.6357**	0.5833	0.5569	**0.1243**	0.4167	0.4769	**0.0464**
23100 35251	Track roller 320	15.7804	13.7811	**2.2229**	1.6667	1.3384	**0.2223**	4.8333	4.3768	**0.1523**
23101 16880	Drag bit	8.3318	6.0668	**1.0991**	3.5833	2.6699	**0.4946**	20.25	16.8336	**0.7546**
Min Error		1	0	5	0	0	6	1	0	5

In this study, Holt-Winters method parameters were set to $\alpha=1$, $\gamma=1$, and $\delta=1$. While these settings prioritize the most recent data—potentially contradicting general data smoothing principles, especially with limited or noisy historical datasets—this decision was supported by empirical testing and a detailed sensitivity analysis on B.T. MINING Co., Ltd.'s spare parts consumption data.

The empirical results showed that the $\alpha=1$, $\gamma=1$, $\delta=1$ parameter settings yielded the lowest forecasting errors (e.g., MAE, RMSE, MAPE) compared to other tuned parameter configurations, including theoretically recommended default values. Furthermore, the sensitivity analysis confirmed that model performance was highly sensitive to changes in these parameters, with values closer to 1 providing the ** most accurate forecasting results** for the specific characteristics of the spare parts consumption data examined.

3.4 Economic Order Quantity (EOQ)

The EOQ model in Eq. (7) determines the most economical order quantity by incorporating price data, spare parts quantity and other related costs.

3.4.1 Ordering Cost (Co)

Based on the collected data, the ordering cost is calculated as 6.54 baht per piece per order can be calculated as shown in **Table 13.**

Table 13 Spare parts order cost per piece per time

Order Cost			
List	**Detail**	**Price**	**Cost (Baht/ time)**
1. Telephone bill	1) phone call per order	3 Baht per time	3.00
2. Purchase Order Approval Document Fee	1) 1 OP card per order 2) Quotations Per Order	1 baht	3.00
3. Labor costs	1) Employee salary 12,000 baht 2) It takes 2 minutes for the purchasing staff to prepare the order documents	Wage = $\frac{12{,}000 \text{ baht}}{43{,}800 \text{ min}}$ = 0.27 Baht per minute	0.54
Total			6.54

3.4.2 Carrying Cost (Cc)

The company's data indicates that the spare parts storage cost is. 1.5% per unit per year, including the opportunity cost of capital tied up in spare parts instead of being invested elsewhere for profit. With the current interest rate at 7.5% per annum (as of January 2024), the total storage and opportunity cost amount to 9% of the spare part's price per year. For example, a Final Drive part costing 182,000 baht incurs a storage cost of 9%, equating to 16,380 baht per piece per year.

1) Economic Order Quantity (EOQ)

$$EOQ = \sqrt{\frac{2CoD^*}{Cc}} \quad (8)$$

From the Eq. (8), the most economical order quantity per order is 0.04. Because spare parts need to be reserved, the EOQ should be an integer, therefore the quantity is rounded up from 0.04 to 1.

2) The number of orders per year is 2 times per year that calculated by using Eq. (9)

$$\text{Order quantity per year} = \frac{D^*}{Q^*} \quad (9)$$

3.5 Fixed Order Quantity (FOQ)

Fixed order quantification is divided into two groups: one with a coefficient of variation less than 0.25 that has passed the EOQ analysis step, and another with a coefficient of variation greater than 0.25 in this group that includes group B spare parts.

3.5.1 Results of Determining the Fixed Order Quantity of Spare Parts Group 1

1) Safety Stock (SS): Calculating Standard Deviation of Demand Rates, (σ-D.) The demand data over six years are 2, 2, 3, 1, 3, and 1 time, respectively, with an average value of 2 times as shown in Eq. (10) as 0.82.

$$\sigma_D = \sqrt{\frac{\sum (x_i-\bar{x})^2}{n}} \quad (10)$$

The confidence level is set at 90% (Z = 1.28) and lead time (LT) is 2, hence SS can be calculated as 1.48 items in Eq. (11)

$$SS = Z \times \sigma_D \times \sqrt{LT} \quad (11)$$

2) Reorder Point (ROP): Using the Final drive spare parts list as an example, the calculation requires requires the data on the number of orders per year (D) obtained from the previous EOQ calculation, which is 2 times per year or 0.005 times per day. This value is then multiplied by the lead time (LT) of 2 days, and added to the safety inventory (SS) with 90% confidence level equal to 1 piece as shown in Eq. (12).

$$ROP = (D \times LT)+SS \quad (12)$$

The calculation results provide the analysis of the economical order quantity. and the reorder points for the six spare parts in Group 1 as shown in **Table 14**.

Table 14 Economic order volume and reorder point of the spare parts list group 1

NO	Spare Parts	Forecast 2024	Order Cost (bath)	Storage costs 9% (bath)	EOQ (item/time)	Order quantity (Times/Year)	Safety Stock (item)	Reorder Points (item)
1	Final drive	2	6.54	16,380.00	1	2	1	2
2	Drag bit	42	6.54	720.00	1	42	6	7
3	Rotary head (SET)	2	6.54	11,252.16	1	2	5	5
4	Air hose	1	6.54	3,555.00	1	1	4	4
5	Bit sub	5	6.54	1,755.00	1	5	13	14
6	Track roller 320	11	6.54	342.00	1	11	4	4

3.5.2 Results of Determining the Fixed Order Quantity of Spare Parts Group 2

1) Safety Stock (SS): The calculation follows the same method as that used for Group 1 spare parts with a confidence level at 90% (Z=1.28). For hydraulic oil cooler spare parts, the safety stock is 2 pieces.

2) Calculating order cycle N: The calculation provides an example using the hydraulic oil cooler spare parts which have an EOQ value of 1 piece. The average annual demand, based on data collection is 0.67 time, as in Eq. (13).

$$\begin{aligned}\text{Order cycle time} &= \frac{Q^*}{D} \\ &= \frac{1}{0.67} \\ &= 1.50 \text{ year}\end{aligned} \quad (13)$$

From the calculation, the order cycle and the required safety stock for the second group of spare parts can be summarized as shown in **Table 15**.

Table 15 Order cycle and spare parts inventory of group 2 spare parts

NO.	Spare Parts	EOQ (item/time)	Order cycle time (Year)	Safety Stock (item)
1	Hydraulic oil cooler	1	1.50	2
2	Drill pipe	1	0.86	2
3	Cartridge at hydraulic pump	1	1.50	2
4	Front idler 320	1	0.50	1
5	Top sub	1	0.75	17
6	Sprocket	1	0.86	5
7	Wire rope	1	0.17	11
8	Dust filter	1	0.25	9
9	Carrier	1	0.60	1

Table 15 Order cycle and spare parts inventory of group 2 spare parts (cont.)

NO.	Spare Parts	EOQ (item/time)	Order cycle time (Year)	Safety Stock (item)
10	Chain link + pin	1	0.35	6
11	Dust hose	1	6.00	1
12	Drive shaft	1	0.75	2
13	Air Throttle Cylinder (SET2)	1	0.75	2
14	Gear box (SET)	1	0.86	3
15	Undercarriage System (SET)	1	0.75	2
16	Mast cylinder (SET3)	1	1.50	1

3.6 Cost of managing spare parts inventory

The analysis of spare parts management for Group 1 and Group 2 was conducted by comparing the total cost, which includes ordering costs and storage costs, along with the order quantity per cycle and average demand. The total inventory cost of spare parts before and after the adjustment is presented between January 2018 to December 2023 (6 years) in **Table 16**.

Table 16 Comparison of costs before and after inventory management

Spare Parts	Order Cost (Baht)	Storage order fee (Baht)	EOQ (Item/Time)		Number of Orders (Times/Year)	Total cost before renovation (Baht)	Total cost of improvement (Baht)
Final drive	6.92	16,380.00	0.04	1	2.00	32,763.27	8,203.08
Drag bit	6.92	720.00	0.90	1	42.00	1,854.94	634.68
Rotary head (SET)	6.92	11,252.16	0.05	1	2.00	11,258.70	5,639.16
Hydraulic oil cooler	6.92	13,770.00	0.03	1	0.67	6,889.36	6,889.36
Air hose	6.92	3,555.00	0.06	1	1.00	1,784.04	1,784.04
Bit sub	6.92	1,755.00	0.20	1	5.00	1,771.35	910.20
Drill pipe	6.92	5,805.00	0.05	1	1.17	5,808.82	2,910.13
Track roller 320	6.92	342.00	0.67	1	11.00	1,376.99	242.94
Cartridge at hydraulic pump	6.92	3,513.78	0.05	1	0.67	3,515.96	1,761.25
Front idler 320	6.92	1,152.00	0.16	1	2.00	1,158.54	589.08
Top sub	6.92	1,620.00	0.11	1	1.33	1,624.36	818.72
Sprocket	6.92	1,782.00	0.10	1	1.17	3,565.91	898.63
Wire rope	6.92	202.50	0.63	1	5.83	221.58	139.40
Dust filter	6.92	261.00	0.46	1	4.00	528.54	156.66
Carrier	6.92	378.50	0.25	1	1.67	383.95	200.15
Chain link + pin	6.92	159.30	0.50	1	2.83	168.57	98.18
Dust hose	6.92	1,643.76	0.04	1	0.17	822.97	822.97
Drive shaft	6.92	117.00	0.40	1	1.33	121.36	67.22
Air Throttle Cylinder (SET2)	6.92	103.05	0.42	1	1.33	60.25	60.25
Gear box (SET)	6.92	116.55	0.37	1	1.17	467.15	65.91
Undercarriage System (SET)	6.92	88.20	0.46	1	1.33	92.56	52.82
Mast cylinder (SET3)	6.92	165.06	0.24	2	0.33	331.21	166.15
					Total	76,570.36	33,110.97

Total cost before the improvement of spare parts inventory management: The ordering cost per spare part per order includes the telephone bill, purchase order approval document fee, and labor costs. The initial analysis revealed that the total cost of managing spare parts inventory was 76,570.36 baht, comprising 22 spare parts from Group 1 and 2 spare parts from Group 2. After implementing the inventory management improvements, the total cost decreased by 33,110.97 baht, resulting in annual cost saving of 43,459.39 baht, equivalent to 56.76%. This indicates that storage costs were significantly high.

4. Conclusion

The analysis of spare parts inventory over the past six years has identified 43 frequently replaced components. This research has proposed optimization strategies using EOQ and FOQ techniques, leading to significant cost reductions.

4.1 ABC Analysis

The analysis of spare parts with maintenance history and order history over the past six years, using the ABC analysis technique for prioritization, categorizes spare parts into Group A, B, and C. The results include the number of spare parts, usage value, percentage of total usage value, and percentage of total spare parts items, covering a total of 43 items, as shown in **Table 2**.

- Group A consist of 9 spare parts, representing 20.93% of the total spare parts list and accounting for 90.44% of the total spare parts usage value.
- Group B includes 13 spare parts, making up 30.23% of the total spare parts list and contributing to 8.67% of the total spare parts usage value.
- Group C comprises 21 spare parts, constituting 48.84% of the total spare parts list and 0.89% of the total spare parts usage value.

These findings highlight the distribution of spare parts usage and their significance in inventory management.

4.2 Forecasting

Minitab Statistical Software was used for forecasting, employing three forecasting models: (1) Moving Average Forecasting, (2) Exponential Smoothing Forecasting, and (3) Winters' Method. (y-axis) The model with the lowest prediction error evaluated using MAPE, MAD, and MSD (x- axis) was identified as Winters' method as shown in **Figure 11**.

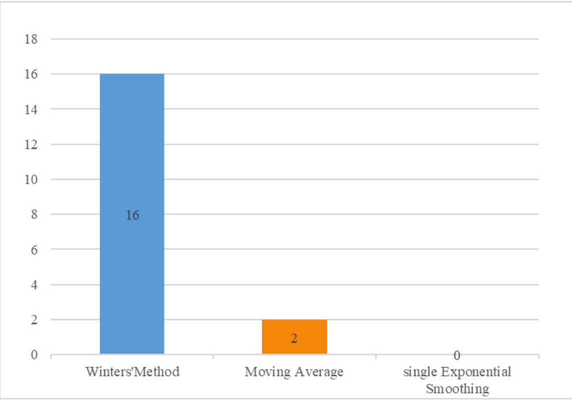

Figure 11 Number of Index Items, Least Error Forecast Margin Estimation

Forecasting using Winters' Method resulted in the fewest instances of the minimum forecast error evaluation index, totaling 1 6 occurrences. This is higher than Moving Average and Exponential Smoothing, which had the fewest instances of the minimum forecast error evaluation index at 2 and 0 occurrences, respectively. Therefore, Winters' Method was selected for forecasting.

4.3 Total cost comparison

The comparison of total costs before and after the adjustment of both the spare parts list of Group 1 and Group 2 is presented in **Figure 12**.

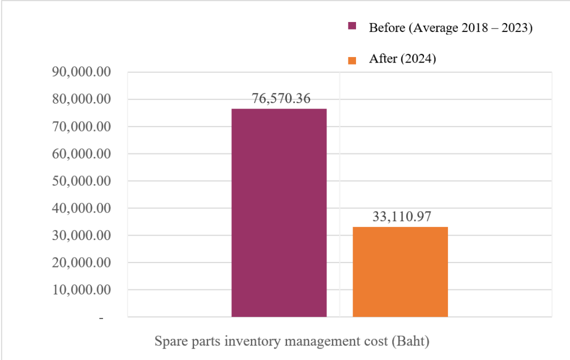

Figure 12 Comparison chart of total cost of spare parts inventory management before and after renovation

After the renovation of spare parts inventory management, the total cost decreased from 76,570.36 baht to 33,110.97 baht, resulting in total cost savings of 43,459.39 baht, or 56.72% of the cost before the renovation.

4.4 Creating a Parts Order Plan

The spare parts ordering plan is categorized into two groups, designed to enhance ease of understanding for operators and reduce the workload at the spare parts counter.

- Group 1 Spare parts ordering plan: This plan follows the most economical order quantity and a newly established reorder point. Spare parts withdrawals and receipts are recorded in real time. Additionally, a program has been developed to enable automatic color changes in the spare parts compartment display, reflecting the current inventory levels. This visual aid enhances clarity for operators and simplifies inventory monitoring.
- Group 2 Spare parts ordering plan: This plan is based on a fixed order quantity, with a predetermined safety stock level that represents the minimum inventory threshold. Spare parts must not be allowed to fall below this level, and an order cycle is established accordingly. The researcher also implemented an automatic color change program similar to that used for Group 1. However, in this case, the color changes are based on the time remaining until the next order cycle rather than current inventory levels.

4.5 Simulation model

The simulation model for spare parts quantity in each process shows the number of spare parts items under each inventory management technique. As depicted in the figure, the first step involves prioritizing spare parts inventory, resulting in a total of 43 items categorized into Group A (9 items), Group B (13 items), and Group C (21 items). For Group A, the coefficient of variation is calculated: 6 items have a coefficient of variation less than 0.25, and 3 items have a coefficient of variation greater than 0.25. Subsequently, these are divided into two groups: Group 1, comprising items with a coefficient of variation less than 0.25, utilizes Forecasting, Economic Order Quantity (EOQ), and Fixed Order Quantity (FOQ) techniques (6 items). Group 2, including items with a coefficient of variation greater than 0.25 and all Group B items, employs the Fixed Order Quantity (FOQ) technique (16 items). Therefore, the total number of spare parts items in the inventory management simulation is 22 upon completion of the process in **Figure 13**.

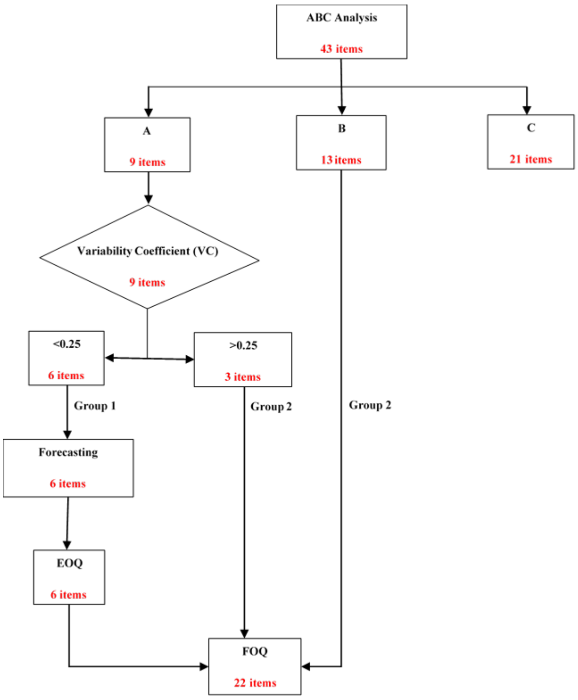

Figure 13 Spare parts quantity simulation for each technique

5. Suggestion

- This research focuses on the spare parts inventory in Group A, which consists of the most valuable and critical items, and Group B, which is the second most important group after Group A. Therefore, the spare parts inventory in Group C was not analyzed. Further research may extend the analysis to include Group C to further enhance the efficiency of spare parts inventory management.
- This research applies the EOQ and FOQ techniques to determine the optimal order quantity. However, various ordering methods are widely used in the manufacturing industry, and each industry can adopt the most suitable approach to achieve the most effective ordering strategy and minimize operating costs.
- This presents an opportunity for further research, comparing these techniques with traditional methods used in the field in **Table 17**.

Table 17 Theoretical evaluation

Topic	**Research Methodology**	**Consistency with Croston / SBA**
Classification by VC	Use VC to separate groups with high variability	Similar to Croston's principle emphasizing intermittent demand
Use of FOQ	Used for groups with VC ≥0.25	Should consider using Croston or SBA instead of FOQ, which does not account for demand patterns
Forecasting	Use Moving Average, Exponential Smoothing, Winters'	Suitable for regular demand but not suitable for intermittent demand
Model Evaluation	Select model based on error values (MAPE, MAD, MSD)	Is a standard criterion but does not yet consider intermittency, for which Croston/SBA is more suitable

6. Acknowledgments

The researcher would like to express their gratitude to B.T. Mining Company for their support and valuable contribution to this research. Special thanks are extended to Mr. Thomas Granderath, Project Manager, Mr. Apisak Jumpit, Mining Engineer, and Mr. Pisanu Pintasa, Mining Engineer, for providing essential information and insights that greatly facilitated this research.

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