Shortage and Dead Stock Mitigation in Heavy Equipment Spare Parts Warehouse Using Integration of ABC Analysis Methods, Analytic Hierarchy Process and EOQ

Dikky Putra Rupawan and Dendi P Ishak
Industrial Engineering Department, Faculty of Engineering
Universitas Indonesia
Depok, Jawa Barat, Indonesia
dikky.putra11@ui.ac.id, dendi@ui.ac.id

Abstract

The growth of industries that use heavy equipment in Indonesia continues to increase so that the use of spare parts has also increased significantly. Most of these spare parts are still imported from outside so that the need for warehouse storage in Indonesia. Spare parts are included in the perishable goods commodity and are urgently needed to support the operations of a unit, however, currently many are still being managed not in accordance with the principles of good warehouse practice. The spare parts warehouse has many types of items, so there is a need for grouping to suit different levels of importance and usage, so it is necessary to align these priorities as a reference for further inventory management with the aim of mitigating shortages and dead stock inventory. This study only focuses on the type of fork-lift and for the flow of research it is carried out by grouping all items into three classes according to the abc analysis rules, then the three classes are continued with Multi-Criteria Decision Analysis that is Analytic Hierarchy Process to get the priority ranking. After that, from the ranking results, the highest ranking is taken indicating the highest priority will be managed further with economic order quantity in the hope that inventory management for parts with the highest priority class can be managed better.

Keywords
Spare parts, Warehouse, ABC Analysis, Analytic Hierarchy Process and Economic Order Quantity.

1. Introduction
The growth of industries that use heavy equipment such as the mining, construction, agriculture and other sectors has resulted in the development of heavy equipment sales in Indonesia. Basically, the trend of heavy equipment sales in Indonesia is closely related to the after sales of each brand to satisfy and attract customers, in this case spare parts are the main key in after sales of heavy equipment sales. Only a few spare parts for heavy equipment brands in Indonesia are produced domestically and most of them are imported from abroad. That way, the importer needs to provide a warehouse for storage of imported spare parts. Spare parts warehouse management must be managed properly to avoid technical and non-technical problems that can cause losses to the company. According to (Irene Roda et al) Warehouse spare parts with commodity goods that are easily damaged and urgently needed to support the operations of a unit, but currently many are still being managed not in accordance with the principles of good warehouse practice.

From data (Figure 1) on the trend of heavy equipment sales in Indonesia from 2015 to September 2022, it can be seen that fluctuating conditions tend to increase every year. However, there has been a decline in the last 2 years, namely from 2019 to 2022, at which time there was an outbreak of the Covid-19 pandemic throughout the world which required world life to be temporarily paralyzed for the industrial sector.

Demand for spare parts is specific and different compared to other materials such as products or intermedia which are fast moving materials with regular requests, demand patterns for spare parts can be slow moving, irregular, intermittent or other demand patterns (Conceicao et al 2015). Warehouses with commodity spare parts have thousands of types of goods, it is necessary to group them in an integrated manner and these goods have different levels of importance and use, so that there is a need for priority alignment as a reference for further management of the inventory system.

(Cavalieri et. al. 2008) proposed a spare parts control framework into 5 (five) stages, namely coding, classification, demand forecasting, inventory management policies, and policy testing and validation. By conducting this research, it is hoped that there will be a change in activities to preventive maintenance for more optimal Warehouse management.

Figure 1. Heavy Equipment Sales Trends in Indonesia
Source: DataIndustry Research, Hinabi, and other sources.

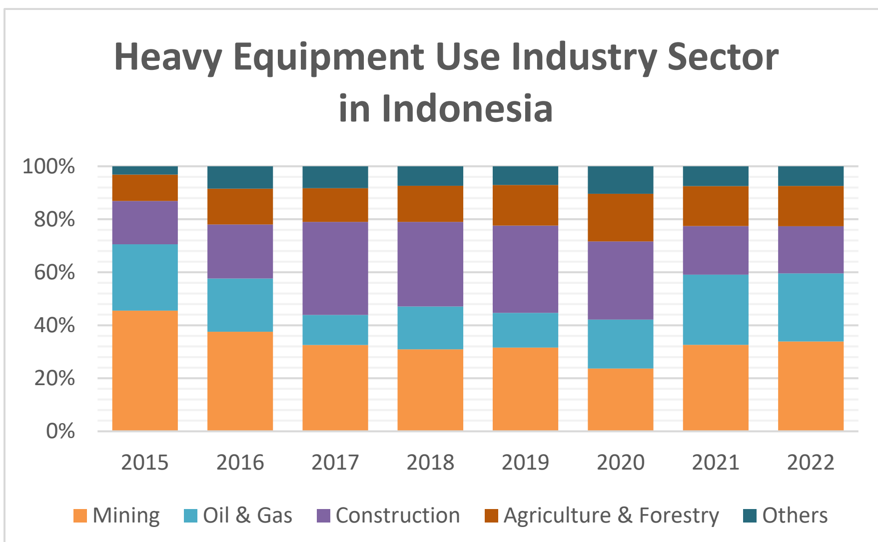

Figure 2. Heavy Equipment Use Industry Sector in Indonesia
Source: DataIndustry Research, Hinabi, and other sources.

The high cost of inventory, the costs and time that must be incurred due to unit breakdown due to the unavailability of spare parts material when needed, and the ineffective management of spare parts warehouse management. In this case, there are not many warehouses for heavy equipment spare parts, there are not many methodologies for classifying types and priority levels of use as a reference for warehouse management (Figure 2). This is because it still relies on reactive/corrective maintenance activities where when the unit is damaged or needs replacement of new spare parts at that time the workshop needs the necessary spare parts. Even though preventive/proactive maintenance activities are needed to reduce the negative impacts that arise for the company. This can be implemented by classifying spare parts according to the criteria for the level of importance and priority to be followed up with effective warehouse management.

1.1 Objectives
Based on the background described above, the formulation of the research problem is how to determine the most appropriate way to mitigate shortages and dead stock inventory by using the abc classification of spare parts analysis, then determining the level of importance and use based on experts with an analytical hierarchy process (AHP) and the result alias tone of further inventory management with economical order quantity (EOQ). Thus, it is expected that there will be significant changes in the inventory management system

2. Literature Review
According to Bahagia, (2006) The inventory system is an idle resource whose existence awaits further processing. The next process is production activities as found in manufacturing, marketing activities as found in distribution systems and so on. Based on a literature study of similar previous studies, there are several advantages and disadvantages in each study that can be used as guidelines in this study. The research entitled A classification approach based on the outranking model for multiple criteria ABC analysis. Jiapeng Liu et al (2016) used AHP and abc analysis to clustering data based on rank from the results of AHP criteria so that optimal results were obtained for grouping goods.

Catarina Teixeira et al (2018) created a policy to prevent shortages in spare parts warehouse management by grouping abc classifications and then mapping out the criteria for expert polling. In this case the results of the policy are strongly influenced by the criteria for the results of the AHP expert questionnaire.

According to Ben-Daya et al (2009) Spare parts are designed for specific uses, usage patterns are highly random, and charging waiting times vary and are often unknown. In addition, these parts are subject to wear and tear or degradation while in storage, and are virtually non-resaleable. Therefore, a procedure is needed to select components that must have spare parts in stock.

In some companies, the cost of storing spare parts can give rise to production costs significantly. With this storage cost, the company is required to be able to manage the procurement and storage of spare parts stock. The purpose of this spare parts management is to reduce the downtime of equipment or units that are long enough to cause failures and losses caused by poor spare parts management. Even so, not all spare parts material can be stored in the warehouse because it is related to the increase in storage costs so that it is necessary to have management, in this case the priority of providing spare parts stock in the warehouse in accordance with the level of importance and use. Parts are designed for specific uses, usage patterns are highly random, and fill lead times vary and are often unknown. In addition, these parts are subject to wear and tear or degradation while in storage, and are virtually non-resaleable. Therefore, a procedure is needed to select components that must have spare parts in stock (Ben-Daya et al. 2009).

3. Methods
There some Method in this research:

a) The initial stage of this research was discussing with the supervisor to determine the background, formulate the problem, determine research gaps and set research objectives.
b) The data collection stage will be divided into two main parts, namely primary data collection and secondary data collection. Primary data will be obtained through interviews with several stakeholders in the PT Trakindo Utama case study spare parts warehouse to obtain comprehensive results from the point of view of experts in the field. Meanwhile secondary data will be collected from SAP system data regarding ABC and EOQ analysis data.
c) At this stage, the raw data processing will be carried out by grouping ABC Analysis into data ready for analysis. After that, the data analysis process is carried out through the Analytical Hierarchy Process (AHP) method to produce critical criteria according to the level of use and the final results of groups that have these critical criteria will be managed by a warehouse management system, namely EOQ.
d) At this final stage, the results will come out in the form of which the group will be managed by the management of the warehouse management system. After that, conclusions are drawn and suggestions for further research are carried out in order to produce better and more comprehensive research.

4. Data Collection

In this study, samples were taken in one of the heavy equipment logistics industries in Indonesia. The data taken is secondary data available in ERP SAP including spare parts of the lift-truck/fork-lift unit type. The data will be managed further by grouping ABC analysis by dividing it into three classes, namely class A, B and C based on the type of goods, the amount of goods used and the unit price of goods.

Primary data taken is in the form of qualitative data through discussion/brainstorming and questionnaires to experts in the warehouse section with mutli criteria AHP decision making to determine the level of importance and usage using 4 criteria namely lead times, criticality, unit price and demand pattern.

Then determine the level of importance and use of a class that has been grouped with ABC analysis, only 1 class will be selected which will be continued for the management of the warehouse management system with the economic order quantity (EOQ). The data needed for the EOQ are the number of requests per year, the cost of each order, the cost of holding goods per unit, the price of goods, the percentage of holding costs and the lead time for procurement of goods.

According to Poras (2008), the classification of spare parts is divided into several different classes in regard to different inventory control methods for different classes, the class classifications are critically, demand, and price. Lead time, unit demand, and critically parts are steps that need to be considered in inventory control.

Teixeira (2018) classifies spare parts by paying attention to criticality based on the impact and function on production as well as inventory management criteria, namely lead time and unit price. Some of the points resulting from the thoughts of previous researchers do indeed play an important role in controlling the supply of spare parts.

5. Results and Discussion

After performing several surgeries as previously mentioned, this study showed promising results. The abc analysis grouping shows a clear distribution of class divisions, selection and alternative withdrawals from the class division results on abc analysis with AHP showing the pattern of class ranking results, to support further inventory management will be followed by EOQ. The detailed explanation will be explained below.

5.1 ABC Analysis Calculation

At this stage, ABC analysis data is processed by withdrawing existing data, namely lift-truck data for 8093-line items. Data taken in the form of types of goods, the number of goods and the total price. From the 8093-line item data, it is processed by cumulatively classified into three classes as shown in Table 1.

Table 1. Result of Abc Analysis

	Class			
Type	**A**	**B**	**C**	**Price ($)**
Engine	162	-	-	IDR 22,569,233,550.00
Undercarriages	22	-	-	IDR 2,990,442,600.00
Accessories	-	8	-	IDR 27,654,450.00
Drivetrain	-	1576	-	IDR 4,869,877,050.00
Electronics	-	84	-	IDR 260,824,950.00
Filters	-	47	-	IDR 160,146,150.00
Fluids	-	7	-	IDR 22,917,750.00

Hydraulics	-	329	-	IDR 1,024,161,150.00
Fasteners	-	-	5858	IDR 2,128,001,850.00
Total	8093			IDR 34,053,259,500.00

5.2 Analytic Hierarchy Process

AHP data collection was carried out by way of discussion/brainstorming and questionnaires to several experts in a professional environment, especially in the warehouse department. In order to obtain a more comprehensive and highly credible assessment result with the requirement of work experience of more than five years and a minimum position of section head with the hope that the results obtained will be objective based on knowledge and experience in the field. In determining the level of importance and use using four criteria namely lead times, criticality, unit price and demand pattern. Meanwhile, there are three alternatives, namely class A spare parts, class B spare parts and class C spare parts.

Table 2. Result of Respondent Based on Citeria

Respondent	LT vs CRIT	LT VS UP	LT vs DP	CRIT vs UP	CRIT vs DP	UP vs DP
1	0.11	7.00	0.20	7.00	7.00	0.17
2	0.14	0.13	0.13	7.00	7.00	0.13
3	0.20	6.00	6.00	1.00	4.00	2.00
4	5.00	6.00	5.00	0.33	0.25	6.00
5	6.00	0.11	0.14	0.13	0.13	7.00
Geomean	0.62	1.28	0.64	1.15	1.44	1.12

From the results of processing the questionnaire in the form of a matrix on this criterion, the same thing is done for alternatives by comparing alternatives to each other to get the desired results (Table 2).

After that, the priority scale is sought from the criteria and alternative parameter table. In AHP there are several important parameters that must be considered to produce consistent and proper AHP calculations. These parameters are Eigen Value, Consistency Index and Consistency Ratio. The Eigen Value is obtained from the sum of the multiplication between each element of the Eigen Vector and the number of paired matrix columns. The Eigen Value is then used to calculate the Consistency Index from pairwise comparisons (Table 3).

Table 3. Random Consistency Index

Matrix Size	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.1	1.45	1.49

The RI value which has been classified by Saaty (1994) is a measure of the consistency limit of a parameter. The classification was obtained through a sample experiment where if numerical calculations were carried out randomly from a scale of 1/9, 1/8, …, 1, 2, …, 9, the average consistency value would be obtained as in Table 3. In this study, the RI value was used. of 0.90 because of four parameters in a 4 x 4 matrix kriteria and 0.58 because there are three parameters resulting in a 3 x 3 matrix alternative calculation in this study.

Table 4. Calculation of AHP Criteria Parameters in Research

AHP Parameter	Value
Eigen Value	4,1

CI	0,02
RI	0,9
CR	3%

Table 4 represents the calculation of AHP criteria parameters in research and Table 5 shows the calculation of AHP alternative parameters in research.

Table 5. Calculation of AHP Alternative Parameters in Research

AHP Parameter	Value LT	Value Crit	Value UP	Value DP
Eigen Value	4,07	4,06	4,07	4,02
CI	0,02	0,02	0,02	0,01
RI	0,58	0,58	0,58	0,58
CR	4%	4%	4%	1%

After having a consistent comparison matrix, the next step is calculating the matrix square to determine the Eigen Vector (EV). The matrix square calculation can be iterated until reaching a stable state of the matrix, in which the difference of each Eigen Vector is equal or close to zero (Table 6).

Table 6. Criteria Matrix Multiplication Calculation: Third Iteration

Criteria	LT	CRIT	UP	DP	S.O.C	Eigen Vector	2nd EV - 3rd EV	
LT	19140,45	12471,77	17400,55	16162,66	65175,43	0,21135	LT	0,000
CRIT	28248,39	18406,43	25680,57	23853,64	96189,02	0,31192	CRIT	0,000
UP	20930,37	13638,07	19027,77	17674,12	71270,33	0,23112	UP	0,000
DP	22242,32	14492,93	20220,46	18781,97	75737,67	0,24560	DP	0,000
Total					308372,46	1		

Table 7 shows the matrix multiplication of alternatif lead time dan criticality and Table 8 shows multiplication of alternatif unit price dan demand price.

Tabel 7. Matrix Multiplication of Alternatif Lead Time dan Criticality

Iteration 1	Iteration 2	Iteration 3	Iteration 1	Iteration 2	Iteration 3
Lead Time			Criticality		
0,62269	0,00572	-0,61139	0,51632	-0,04883	-0,74784
0,12120	-0,00572	-0,13243	0,12815	-0,02793	-0,21974
0,25611	0,00000	-0,25619	0,35198	-0,02585	-0,49527

Tabel 8. Matrix Multiplication of Alternatif Unit Price dan Demand Price

Iteration 1	Iteration 2	Iteration 3	Iteration 1	Iteration 2	Iteration 3
Unit Price			Demand Price		
0,61334	0,04105	-0,44526	0,52446	-0,09253	-0,99023
0,10727	0,00716	-0,07791	0,15086	-0,05146	-0,34278
0,26529	0,01774	-0,19261	0,32736	-0,05165	-0,60697

The calculation of the square matrix multiplication to determine the eigenvector is carried out on the criteria and alternative parameters. after the result is close to or equal to zero. then the iteration of the calculation will be a reference for determining the final result of the AHP ranking.

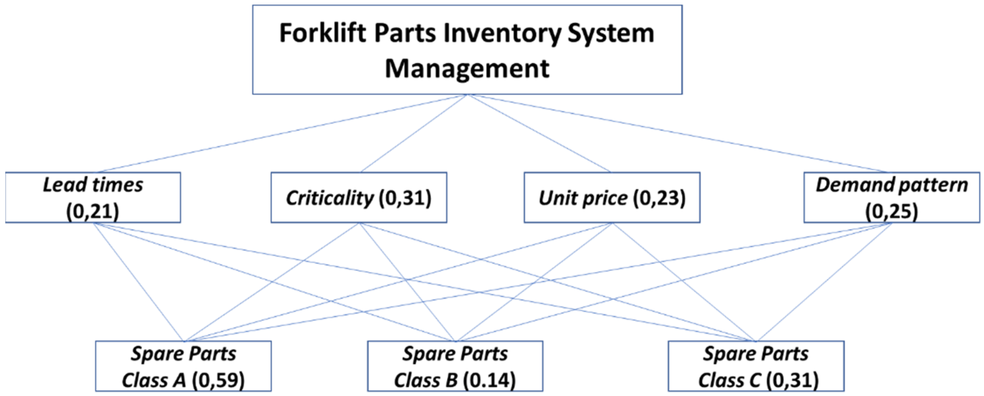

Figure 3. Decision Analysis (AHP) Framework

Figure 3 is the result of a decision analysis framework where from the four criteria a lead time is found with a score of 0.21, criticality of 0.31, unit price of 0.23, demand pattern of 0.25. then in Tables 9 and 10 for the three alternative parameters found spare parts A with a score of 0.59, spare parts B 0.14, spare parts C 0.31.

Table 9. Criteria Result of AHP

Criteria	Rank	%
CRIT	1	31.19%
DP	2	24.56%
UP	3	23.11%
LT	4	21.14%

Table 10. Alternative Result of AHP

ALT	Rank	%
Class A	1	59.29%
Class C	2	31.51%
Class B	3	14.64%

Thus, the results of the AHP decision analysis by experts found that for forklift parts inventory management it was found that criticality is very important in the criterion parameters and spare parts A need to be managed further. These results will be followed up with further inventory management.

5.3 Processing Economic Order Quantity

Economic Order Quantity data is collected in the form of requests per year, the cost of each order, the cost of holding goods per unit, the price of goods, the percentage of holding costs and the lead time for procurement of goods. All types of data will be processed depending on the results of AHP. From the results of the AHP there will be 1 type of class that will be further managed by the EOQ inventory system. In processing, optimal Q, safety stock and reorder points will be sought.

Here Tables 1 and 2 represent the processing EOQ result of class A and final result of EOQ class A respectively. Besides Figure 4 shows the comparison between demand, Q, SS and ROP.

Table 11. Processing EOQ Result of Class A

Type	Qty Items	Demand Years (D)	Holding Cost (H)	Order Cost (S)	Annual Demand (D)	Lead Time	Price (Rp)
Engine	162	119	25,23	9,04	10	3,5	Rp 22.569.233.550,00
Undercarriages	22	17,27	49,19	8,16	2	3,5	Rp 2.990.442.600,00

Table 12. Final Result of EOQ Class A

Type	Qty Items	Q	SS	ROP
Engine	162	10.00	58	35
Undercarriages	22	3.00	12	7

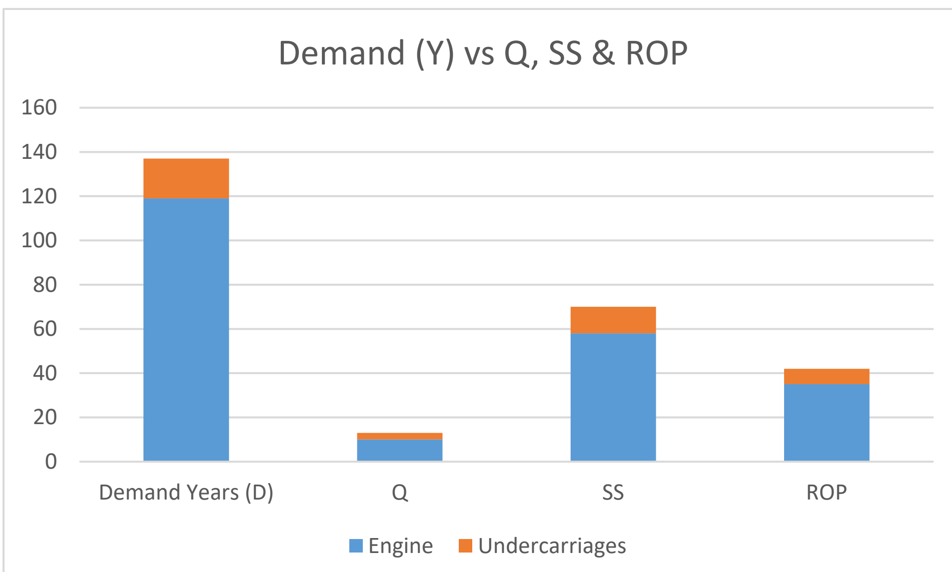

Figure 4. Comparison between demand, Q, SS and ROP

From the results of the EOQ management it was found that spare parts class A consists of parts in the form of engines which must have an optimal Q of 10, a safety stock of 58 and reorder points of 35 and also undercarriages must have an optimal Q of 3, a safety stock of 12 and a reorder point of 7. suggestions This recommendation will become a policy guide in making decisions related to the management of class A spare parts management.

6. Conclusion

This study analyzes the new methods to mitigate shortage and dead stock spare parts inventory using 3 methods that never been put together, so that will be the research gap of this study. we can understand that managing a spare parts warehouse needs good optimization for business continuity. This can be a benchmark for other companies, especially with commodity spare parts. however, there are still sections that can be improved, such as more data usage, choices on more criteria and alternatives in AHP.

References

Assauri, S., Operasi, M. P. D. and Revisi, E., Jakarta: Fakultas Ekonomi Universitas Indonesia, 2004.

Bahagia, S. N., Sistem Inventori. Bandung: ITB, 2006.

Ben-Daya, M., Duffuaa, S. O., Raouf, A., Knezevic, J. and Ait-Kadi, D., Handbook of maintenance management and engineering, *Springer*, vol. 9, 2009.

Cárdenas-Barrón, L. E., A simple method to compute economic order quantities: Some observations, *Applied Mathematical Modelling*, vol. 34, no. 6, pp. 1684-1688, 2010.

Cavalieri, S., Garetti, M., Macchi, M. and Pinto, R., A decision-making framework for managing maintenance spare parts*, Production Planning & Control*, vol. 19, no. 4, pp. 379– 396, 2008.

Chase, R.B., Jacobs, F.R., Aquilano, N.J., and Agarwal, N.K., Operations Management for Competitive Advantage, 11th ed, McGraw Hill, NY, USA, 806p, 2006.

Conceição, S. V., Da Silva, G. L. C., Lu, D., Nunes, N. T. R. and Pedrosa, G. C., A demand classification scheme for spare part inventory model subject to stochastic demand and lead time, *Production Planning & Control*, vol. 26, no. 16, pp. 1318–1331, 2015.

Erlenkotter, D., Ford Whitman Harris and the economic order quantity model*, Operations Research*, vol. 38, no. 6, pp. 937-946, 1990.

Jung, H. and Klein, C. M., Optimal inventory policies for an economic order quantity model with decreasing cost functions, *European Journal of Operational Research*, vol. 165, no. 1, pp. 108-126, 2005.

Kusnadi, E., Analisis produktivitas terhadap penyeimbangan lintasan, Unpublished undergraduate thesis, Program Studi Teknik Industri, Universitas Mercu Buana, Jakarta, 2009.

Liu, J., Liao, X., Zhao, W. and Yang, N., A classification approach based on the outranking model for multiple criteria ABC analysis, *Omega*, vol. 61, pp. 19-34, 2016.

Ng, W. L., A simple classifier for multiple criteria ABC analysis, *European Journal of Operational Research*, vol. 177, no. 1, pp. 344-353, 2007.

Porras, E. and Dekker, R., An inventory control system for spare parts at a refinery: An empirical comparison of different re-order point methods, *European Journal of Operational Research*, vol. 184, no. 1, pp. 101-132, 2008.

Roda, I., Macchi, M., Fumagalli, L. and Viveros, P., On the classification of spare parts with a multi-criteria perspective*, IFAC Proceedings Volumes*, vol. 45, no. 31, pp. 19-24, 2012.

Rubino, S., Mossa, G. and Digiesi, S., Spare parts inventory reduction: A multi-attribute approach, *IFAC Proceedings Volumes*, vol. 43, no. 3, pp. 62-67, 2010.

Saaty, T., Fundamentals of Decision Making and Priority Theory. Pittsburgh: RWS Publications, 1994.

Taha, H.A., Operations research: An introduction, Harlow, England: Pearson, 2017.

Teixeira, C., Lopes, I. and Figueiredo, M., Multi-criteria classification for spare parts management: A case study, *Procedia Manufacturing*, vol. 11, pp. 1560-1567, 2018.

Biography

Dikky Putra Rupawan, is a Master Degree student in Industrial Engineering Department, Faculty of Engineering Universitas Indonesia. He earned his bachelor degree in Geological Engineering from Trisakti University. His research of interest is supply chain management, warehousing, integrated logistics system, quality management and operation management. He is also a working professional in supply chain especially warehousing management in one of biggest logistics company in Indonesia.

Dendi P Ishak, is a lecturer at the Industrial Engineering Department of Universitas Indonesia. He holds a Bachelor Engineering degree and a Master of Engineering Science degree in Industrial Engineering from Wayne State University USA. Mr. Dendi completed his Doctorate in Mechanical Engineering from Universiti Teknologi MARA Malaysia. His filed interest in organizational behaviour and design, industrial project management, Safety Engineering and Management, and Maintenance Management System.