

Joint Optimization of Inventory and Preventive Maintenance: Systematic Literature Review and Research Agenda

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Abstract—Recently, integration between activities in operational areas has more attention to improve and optimize in supply chain management. Joint optimization of inventory and maintenance are one of important activities in achieve operational excellence. Good spare part inventory management aims to minimize buffer time between supply time and demand needs in maintenance activities and operational activities by increasing availability of spare parts at the time required. The authors only focusing on joint spare parts inventory and preventive maintenance. This paper uses sytematic literature review (SLR) as a methodology in reviewing literature. This paper will classified of each research on primary studies by objective function, decision variables, variables, and methods. From the literature review results it is known that joint optimization of spare parts inventory and preventive maintenance can be explored further on multi echelon networks and considering several factors such as deterioration and obsolescence, moreover some papers doing integrated calculations simultaneously not sequential or separately.

Index Terms—joint optimization, inventory optimization, maintenance, preventive maintenance, systematic literature review

I. INTRODUCTION

The existing system in the industry was getting more and more complex day along with a wide range of challenges and boundaries that exist in real world. The increased use of such transportation modes has resulted challenges in facing problems in order to maintain or improve service levels. Spare part demand for transportation modes is increasing frequently by the growth of usage in both distance and cargo, for its primary purpose are to maximize the system availability, minimize inventory cost or maintenance cost. Inventory and maintenance are the important activities in achieving operational excellence. In the implementation of maintenance activities, not infrequently there are components that in case of failure or damage can not be repaired, but must be replaced. Therefore, it is necessary to replace or spare parts, so that the component can be replaced and the system can continue to run properly.

In implementing maintenance activities, there is spare parts as very important component to support one of the operational activities. Good spare part inventory management aims to minimize buffer time between supply time and demand needs, and also aims to have the spare parts available at the time required. This paper aims to conduct a survey of research trends and research agenda related to joint inventory optimization and preventive maintenance. The following is outline of paper structure based on each section. Next section will describe about background information. Section 3 discusses related work which became the basis for work of this survey. The systematic literature review will conducted in Section 4. Result of the systematic literature review is presents in Section 5. In the last section presents conclusion of this paper and proposed model for next research.

II. METHODOLOGY

Systematic review have differences with the traditional review, which is defined by [1] as ‘A method for understanding most of the information of related fields, and the means to provide answers to questions about what works and what does not’. A systematic review is a useful method for researchers to promote their research and implement it. The aim of systematic literature review is tightly specified with the research topics and objectives with a specific review questions, while the aim of traditional literature review is to gain broad understanding and give descriptions about the research topics [2]. This paper used systematic literature review that was applied to identify research trends, variables, and methods on join optimization of inventory and preventive maintenance.

A. Research Questions

This paper aims to collect and investigate variables that has been considered in join optimization of inventory and preventive maintenance studies. This paper also investigate research trends to generate research agenda and identify the most used methods in related topics. Table I. shows the (PICOC) structure of the research questions.

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TABLE I. SUMMARY OF PICOC

Population	Inventory management, maintenance management, locomotive maintenance depot
Intervention	Proposing joint optimization model of inventory and preventive maintenance to minimize operational costs.
Comparison	n/a
Outcomes	Optimal model from joint optimization model of multi echelon inventory and preventive maintenance
Context	Studies in companies that implement inventory and maintenance activities

With referring to PICOC criteria above then further can be identified specific research questions. The following research questions (RQs) are raised that shows in Table II.

TABLE II. RESEARCH QUESTIONS ON LITERATURE REVIEW

ID	Research Question	Motivation
RQ1	Which journal is the most significant in reviewing Joint optimization inventory and pm	Identify the most significant journal
RQ2	What kind of research topics which are often discussed Joint optimization inventory and pm	Identify the research trends
RQ3	What kind of variables considered are used most often for Joint optimization inventory and pm	Identify the most used factors
RQ4	What kind of methods are used most often for Joint optimization inventory and pm	Identify the most used methods
RQ5	What kind of variables which must be considered for the next research in Joint optimization inventory and pm	Identify variables considered for future research

B. Search Query

The purposes of the search process is the identification of the journal articles that investigated joint optimization inventory and preventive maintenance and it focuses on the variables that has not been considered in joint optimization of inventory and preventive maintenance. In this paper, we used online databases to review the search process. The research questions are used to construct a search string in the databases. The search was conducted between 2007-2017.

C. Selection of Sources

The searches conducted to find relevant research in this survey are limited by searching only for journal articles and conference papers in order to obtain valid results. The query strings were applied titles, abstract and body of studies, the search was conducted between 2007-2017 using the online scientific database. Online database included IEEE, Taylor & Francis, Springer, and Elsevier.

D. Study Selection

The next step is doing study selection that focused more on attributes of each journal after we find the relevant journals which have obtained from online database or journal publisher. In the process of selecting the primary studies, we used inclusion and rejection criteria. These criteria are shown in Table III.

TABLE III. ACCEPTED AND REJECTED CRITERIA

Accepted Criteria	Research or studies in industry such as aviation, railway, transportation, etc
	Research or studies discussing joint optimization of inventory and preventive maintenance in the area of industrial engineering and manufacturing
	For research or studies that have both the conference and journal versions
	For duplicate publications of the same research or studies, only the most complete and newest one will be included
	For research or studies that published between 2007 until 2017
Rejection Criteria	Joint optimization inventory and preventive maintenance that considering transportation.
	Research or studies that focus in predictive maintenances
	Research or studies that focus in rolling stock inventory
	Research or studies not written in english

In this survey, we used Mendeley (<https://www.mendeley.com>) as software that used to store and manage the search results. The final list of selected studies for the first stage had 22 primary studies.

E. Data Extraction

The next step is to extraction on selected primary studies to collect data that contribute to answering research questions related to this review. To answer the research question it is necessary to collect data from the primary study to further design the data extraction form. By using research questions and analysis then will be identified data extraction properties. Four properties were used to answer the research questions shown in Table IV. The data extraction is performed in an iterative manner.

TABLE IV. DATA EXTRACTION PROPERTIES MAPPED TO RESEARCH QUESTIONS

Property	Research Questions
Research Publication	RQ1
Research Topics	RQ2
Research Variables	RQ3, RQ5
Research Method	RQ4

F. Significant Journals Publication

This paper was conducted search between 2007-2017 as mentioned in search query section, but there are also additional papers as additional references from related research. The research on joint optimization inventory and maintenance was increased year by year, as proven by the number of related journals that increasing from 2007 until 2017 that shown in Fig. 1.

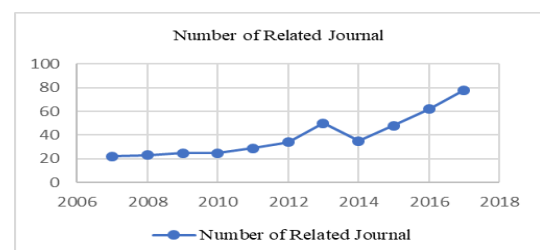


Figure 1. Number of selected studies over the years

This figure shows that the joint topic of inventory optimization and preventive maintenance is still one of the important topics and can develop in further research. According to the selected primary studies, the most important joint optimization inventory and maintenance journals are displayed in Fig. 2. These journal is mostly obtained from European Journal of Operational Research and Reliability Engineering and System Safety.

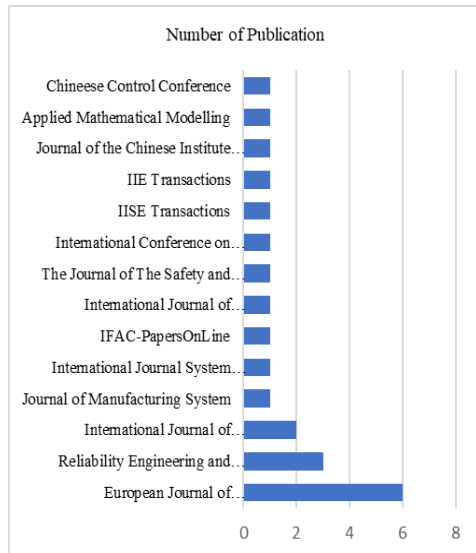


Figure 2. Journal publication of selected studies

G. Research Topics in Joint Optimization of Inventory and Preventive Maintenance

Based on research objectives, we identify two objective function, such as minimize inventory cost and minimize maintenance cost. But, several paper also have both of the objective function such as minimize inventory and maintenance cost. Some studies also have different objective functions such as minimize downtime, increasing service level, related to environmental impact, and increasing safety.

The inventory related cost itself has several cost components such as order cost, shortage cost, and holding cost. While in maintenance related cost also has several components such as inspection cost, economic losses, replacement cost, etc. In fact, there are also studies that focus on both at once, although not all components of inventory related costs and maintenance related costs considered. Other research topics sort the research by maintenance strategies. The maintenance strategies can divided into three types, there are preventive maintenance, corrective maintenance, and predictive maintenance. This research will focus only to preventive maintenance because in railway companies in indonesia has a type of preventive maintenane which has a weekly until annual maintenance schedule to locomotives.

Another research topics also sort the research by networks that divided into several types, such as single echelon networks and multi echelon networks. According to [3] single echelon means the system has only one

management (warehouse and service facility), one supplier, and one or more customers. Multi echelon has a more complex system that consist of several warehouse and service facilities, multiple suppliers, and several customers. Therefore at an early stage this survey will categorize primary studies based on its networks (single echelon or multi echelon), because this is the first step in identifying real cases that shows in Table V.

TABLE V. MAPPING RELATED JOURNAL TO RESEARCH TOPIC

Type of Research Topics	Single Echelon	[4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19]
	Multi Echelon	[20], [21], [22], [23], [24]

H. Most Used Research Variables in Joint Optimization of Inventory and Maintenance

This section will identify characteristics of variable that the most used considered in inventory and maintenance by several research. In this survey, we divide two kinds of characteristics which contained different variables.

1) Inventory characteristics variables

An increasing number of studies in joint optimization of inventory and preventive maintenance that seen from the increase in each year causes the possibility of many variables consider that shown in Fig. 3.

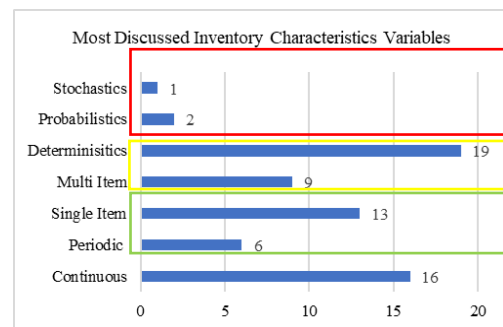


Figure 3. Most discussed inventory characteristics variables

From Fig. 3, we can seen that deterministics is the most discussed type of lead time in inventory characteristics variables. Second, single item is the most discussed type of item in inventory characteristics variables. Last, from inventory, there is continuous as the most discussed inventory policy.

2) Maintenance characteristics variables

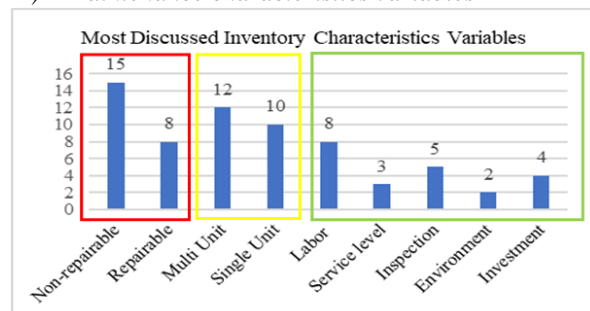


Figure 4. Most discussed maintenance characteristics variables

From Fig. 4, we will explain the most discussed variables in maintenance characteristics. First, labor and service level are the most discussed type of business objectives in maintenance characteristics variables. Second, multi unit is the most discussed type of system in inventory characteristics variables. From inventory, there is continuous as the most discussed inventory policy. Last, spare parts characteristics variables has non-repairable as the most discussed.

I. The Most Used Method in Joint Optimization of Inventory and Preventive Maintenance

In solving joint optimization of inventory and preventive maintenance problem, several authors most commonly uses two type of method, such as simulation or mathematical programming. Mathematical programming will concerns the development of mathematical models based on linear programming, dynamic programming, goal programming [8]. Simulation modelling uses when mathematical programming can not describe non-linear relations, which hard to solve with analytical method. From both types of methods can be seen that mathematical modelling is an optimization techniques, while simulation is not an optimization technique. This problem can be solved by integrating both simulation with mathematical modelling, but this depends on the objective function that was defined previously. This section will shows that several type method (in 2007-2017) used and have been applied in Joint Optimization of Inventory and Maintenance (see Fig. 5).

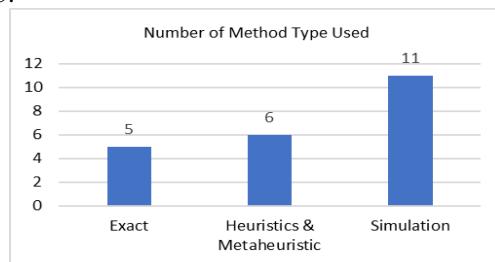


Figure 5. Method used in joint optimization of inventory and maintenance

Fig. 5 shows several type of method from each category such as in exact category there are quadratic formula, dynamic programming etc. From Heuristic, there are Genetics Algorithm, Particle Swarm Optimization, etc. From the three type of methods shown in Fig. 5 in Section E, we know that exact method have 23% application, heuristic & metaheuristics have 27%, and simulation method have 50% application to related topics.

J. Proposed Research Variables in Joint Optimization of Inventory and Maintenance

To find solutions in optimization problems especially joint inventory optimization and preventive maintenance basically depends on the case study and the complexity of the case study. For examples, different characteristics will affect different mathematical models to solve the study case, in this case between single echelon and multi

echelon. Besides, differences in the characteristics of items such as single items and multi item also has a different level of complexity. Thus, in analyzing the problems on a case study needs to be done carefully identifier on each characteristics both inventory characteristics and maintenance characteristics.

There are many research gaps that can be performed on inventory characteristics variables. First, from networks type shows that multi echelon networks not yet explored. This is indicated by number of journal published between 2007 until 2017 that shown single echelon networks has more number than multi echelon networks. Second, from type of lead time, deterministic lead time has the most influence number than probabilistic and stochastic. In real case study, it is rare to find stochastic lead time, because the vendor usually has a definite schedule and if there is a worst case then only delay occurs. Therefore, in future research it can be consider probabilistic lead time into the problem, but it depends on the actual case study, if lead time is certain then it is better to use deterministic lead time. For inventory policy, such as continuous and periodic are depends on the case studies the researchers are trying to solve. In type of item, depends on failure frequencies or lead time of the system, if the failure frequencies are high or lead time of the system are very long, it might be used multi unit than single unit inventory.

In maintenance characteristics variables also have many research gaps which can be investigated in further research. From, spare parts characteristics actually depends on the problem to be discussed due to a system e.g aircraft systems or vehicles in general there are repairable spare parts or non repairable spare parts. On system variables, there are single unit and multi unit systems, if we refer to research that has been done mostly focus more on multi-unit systems because of complexity in system studied rarely solve case of single unit systems. Last, in business objective identified five sub variables, such as labor, service level, environment, inspection, and investment. Based on the most influencing variables in business objective, labor, service level, inspection and investment have considered in some studies. This is because in some case studies rarely consider the environments in the case study.

III. CONCLUSION

This paper presented a systematic literature review on joint optimization of inventory and preventive maintenance. In this study conducted systematic literature review to get research opportunities and research gap which will be examined in subsequent research. This paper also proposed research variables both inventory characteristics and maintenance characteristics that have not been considered in previous research and can be considered in further research. Based on systematic literature review step, we obtained 22 primary studies which are included in the criteria that described in the inclusion and exclusion section. In this paper also shows that studies on joint optimization of inventory and preventive maintenance have increased based on number in each years (2007 until 2017). This paper also proposed

that joint optimization of inventory and preventive maintenance is better to optimize simultaneously not separately or sequentially, because it will affect its output of solution. Our review also proposed that multi echelon inventory still be one of characteristics which still interesting until now.

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