Atlantis Highlights in Engineering (AHE), volume 2
International Conference on Industrial Enterprise and System Engineering (IcoIESE 2018)

INTEGRATED MODEL DEVELOPMENT OF SPARE PART INVENTORY AND MAINTENANCE

1st Prafajar Suksessanno Muttaqin
Faculty of Industrial Engineering
Telkom University
Bandung, Indonesia
prafajar37@gmail.com

2nd Dida Diah Damayanti
Faculty of Industrial Engineering
Telkom University
Bandung, Indonesia
didadiah@gmail.com

3rd Anton Abdulbasah Kamil
Faculty of Industrial Engineering
Telkom University
Bandung, Indonesia
kamil.antonabdulbasah@gmail.com

***Abstract*— This research concerns inventory and maintenance problem of critical spare parts in the locomotive mechanical system in PT KAI Bandung. We proposed periodic review approach in managing spare part inventory, while maintenance interval is preventive maintenance schedule for spare parts. This research is generated by developing integration model of inventory and maintenance on critical spare parts in locomotives mechanical system by considering failure rate, deterioration rate, and imperfect preventive maintenance. The decision variable were maximum inventory quantity and locomotive maintenance interval with the objective function is to minimize total system cost. The integration of inventory and maintenance in this research was solved by analytic model with PSO algorithm. For future research can consider both demand and stochastic lead time. Multi echelon and transport consideration are interesting and combined other algorithm, such as genetics algorithm and tabu search algorithm also be further research.**

Keywords*— *periodic review, failure rates, total system cost, PSO algorithm

I. INTRODUCTION

Transportation services are services with high risk and responsibility, because transportation services move not only goods, but also humans from one location to another location. The system of transportation services which is increasingly complex because the problems faced also have a high complexity. Availability of qualified human resources and other reource is the main key to success in tranportation services, but it is not easy as disscussed because the system and subsystem in the real word has many conditions and constraint. One of the problems that often occurs in this services such as downtime that frequently causes that give impact in departure and arrrival of vehicle. This research uses a case in Indonesian State owned Railway Company especially in operational area II Bandung. PT Kereta Api Indonesia (Persero) or PT KAI is an Indonesian State-Owned Enterprise that provides, regulates, and manages rail transportation services in Indonesia. PT KAI services include passenger transportation, goods and business assets. Currently PT KAI is developing railway facilities and infrastructure to improve connectivity between regions, not only in Java and Sumatra, but also in Kalimantan and Sulawesi**.**

The problem that occurs in this company is downtime that causes higher total system cost. Downtime that became concern in this research is locomotives downtime which cause delay on the train. Downtime frequency of locomotives in year is shown in Fig. 1.

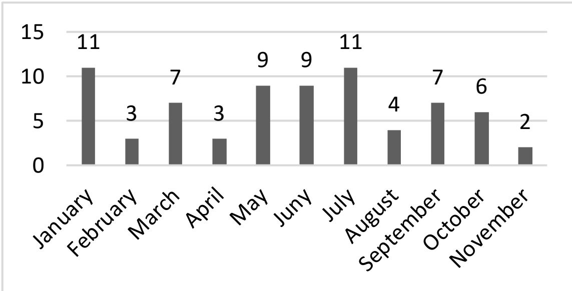

Fig. 1 Downtime Frequency in Year 2017

Based on data obtained from this company, we can concluded that the locomotive downtime cause by two factors, machine malfunction and IT technical problem.. IT technical problem is a failure of the computer system that regulates railway and location of each train, while machine failure is a failure of locomotive caused by malfunction of components that can give impact to train operational activities. Locomotive downtime cause in operational area II Bandung is shown in Fig. 2.

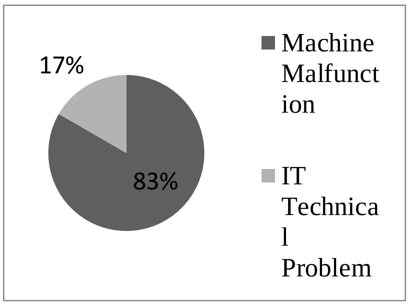

Fig. 2 Locomotive Downtime Cause in Daop II Bandung

In this research, further identification of the causes of downtime in operational area II Bandung. From deep observation, we find that inventory management and maintenance management are cause of these problems. There are Spare part inventory management that is not optimal, especially for critical spare parts. This problem evidenced by the frequent of overstock and stockout of critical spare parts. Critical spare parts are very important spare parts, which is without this item, locomotives engine can not operate. In related company, inventory and maintenance are located at maintenance facility that called dipo. Dipo is facility to store and doing minor maintenance, while Balai Yasa is facility that used to doing medium to large maintenance. Stockout and overstock phenomenon of critical spare part is shown in Fig. 3.

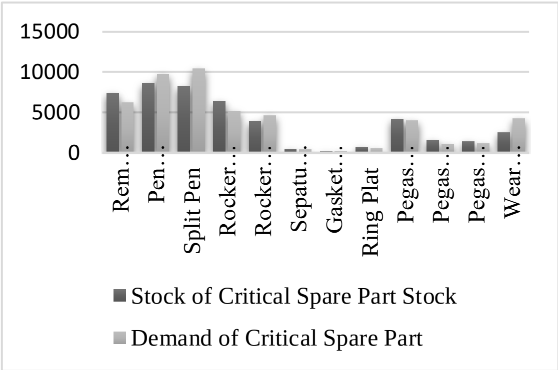

Fig. 3 Critical Spare Part Data in Bandung Locomotive Dipo

Beside occurs inventory management problem, there is maintenance management problem. Maintenance policy in locomotives dipo are divided into preventive maintenance and corrective maintenance. In this case, when maintenance schedules are too often can cause frequent replacemenet of spare parts, but good in avoiding downtime. Whereas if maintenance schedules are too rarely can cause replacement parts are rarely replaced, but it can give impact in frequent downtime. From the probems described, this research focus on integrated model development of spare part inventory and maintennce considering failure rate, deterioration rate and imperfect maintenance for locomotives.

The organization of the paper is as follows, section 2 will describe about related study. Next section discusses about mathematical model of problem related. Section 4 dicusses about discussion and result of problem and last section discusses about conclusion and opportunities for future research.

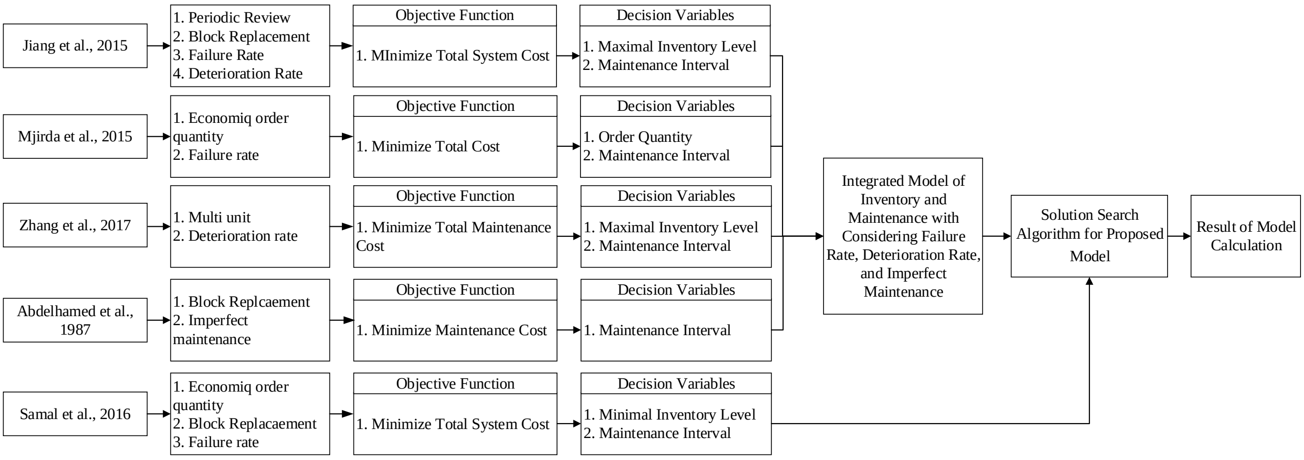

Fig. 4 Integrated Model Development of Inventory and Maintenance

II. RELATED STUDY

Research about joint optimization of inventory and maintenance already much studied previously. Several studies [1] and [2] discussed about joint optimization of inventory and maintenance in systematic literature review form. These research more focuses in mapping research positions, research gap, and research opportunities for future research. In general, spare parts inventory and maintenance policy are solcing separately or sequentally. According to [3], level of spare parts inventory often depends on maintenance policies. Therefore, in solving thes problems will better to do it simultaneously, to produce more optimal solution than solving separately or sequentally. For the next we describe integrated model development of inventory and maintenance in Fig. 4.

Many research of joint optimization of spare parts inventory and maintenance also presented not only in literature but also models have been proposed. Research proposed by [4] discusses about joint optimization of inventory and maintenance for critical and non critical spare part in multi echelon inventory. Another research proposed by (Sheng , 2016) that discussed about joint optimization of spare parts inventory and maintenance in the aviation field. Last research, proposed by [6] discusses about joint optimization of spare parts inventory and maintenance using simulation method. In this research, we consider failure rate, deterioration rate, and imperfect maintenance to solve spare part inventory and maintenance problem. It concerns the periodic maintenance and inventory problem proposed by [7].

III. MODEL

In this section, we describe the system studied. The system that used as a case study on this research is inventory and maintenance system for critical spare parts in Locomotives Dipo II Bandung. The system consist one facility location and many locomotives. Locomotives that are considered in this study are the locomotives owned by Bandung and other areas, so that the inventory system is expected to be able to fulfill the demand for spare parts and maintenance schedules for locomotives. From this explanation the problem can be modeled as.

Subject to :

$$Min\ C \sum_{p=0}^{n} \frac{C_M}{T} + \sum_{p=0}^{n} \frac{C_o}{T} + \sum_{p=0}^{n} \frac{C_S}{T} + \sum_{p=0}^{n} \frac{C_H}{T} \qquad (1)$$

$$\text{With } S_a = S - n - E[X_n(T) - X_n(T-\tau)] - E[Y(T) - Y(T-\tau) \qquad (2)$$

The objective function of the optimization model of inventory and maintenance is minimize the total expected cost per unit time on critical spare parts either owned locomotive operational area II Bandung and belonging to other operational areas. Eq. (1) states that the objective function of the problem raised is the cumulative maintenance cost CM, order cost Co, shortage cost Cs, and holding cost Ch which is then divided by maintenance time interval T. With the next explanation shown in the Eq. (2) stating that the estimated number of critical spare parts stock after replacement of preventive replacement denoted Sa is equal to the cumulative result of the maximum number of critical spare parts stock denoted by S, minus the number of identical components in the system denoted n, minus with the estimated value multiplication with the number of corrective changes with n components in the preventive maintenance interval minus the number of corrective changes with n components in the preventive maintenance interval on a lead time.

$$C_M = C_M.n + C_{cr}.E[X_n] = C_M.n + C_{cr}M[T] \quad (3)$$

$$C_O = K + C_{sp}.(n + e[X_n] + E[Y|] \quad (4)$$

$$C_h = c_h.\left[\int_{0\le X_n+y\le S_a} T.\left(S_a - \frac{X_n+y}{2}\right) dG_{X_n}(X_n)G_y(y) + \int_{X_n+y>S_a} T.\frac{S_a}{2}.\frac{S_a}{X_n+y}\,dG_{X_n}(X_n)G_y(y)\right] \quad (5)$$

$$C_s = c_s.\left[\int_{X_n+y>S_a} T.\frac{X_n+y-S_a}{2}.\frac{X_n+y-S_a}{X_n+y}\,dG_{X_n}(X_n)G_y(y)\right] \quad (6)$$

For the next Eq. (3), (4), (5), (6), described about component of cumulative maintenance cost CM, order cost Co, shortage cost Cs, and holding cost Ch, which will then be accumulated into the total system cost.

$$I'(t) = -g(t).I(t) - d(t) \quad (7)$$

$$(t) = I(0).e^{-\int_0^t g(\tau)d\tau} \quad (8)$$

$$E[y] = S_a - S_a.e^{-\int_0^t g(\tau)d\tau} = S_a\left(1 - e^{-\int_0^t g(\tau)d\tau}\right) \quad (9)$$

$$S_a = S - n - n[M(T) - M(T-\tau)] - S_a\left[e^{-\int_0^{T-\tau} g(\tau)d\tau} - e^{-\int_0^{T} g(\tau)d\tau}\right] \quad (10)$$

$$\tau \le T \le \mu, \quad (11)$$

$$1, S_a = S \quad (12)$$
$$0, S_a < S$$

For Eq. (7) ensure the stock of critical spare part for next period denoted by *I'(t)* is cumulative of critical spare part deterioration inventory which is negative, multiplied by the number of critical spare parts stock currently denoted by (t) then reduced by the level of demand (damage) at time t denoted by (t). Eq. (8) concern about deterioration rate of critical spare parts. Eq. (9) is about expectation model number of stock after preventive replacement, when Eq (10) concern about number of critical spare parts in initial conditions. For Eq (11) ensure that lead time (τ) must be less than the same as the preventive maintenance interval (T) and less than the same as the estimated time of damage to critical locomotive parts. Then Eq. (12) ensure when the time has reached T (T = 1,2,3 .. n), then there is a return decision by looking at the amount of spare parts inventory immediately after the current period preventive maintenance, if the number of spare parts inventory shortly after the current preventive maintenance period is smaller than the maximum inventory value, spare parts can be ordered and vice versa.

IV. DISCUSSION AND RESULT

As described in introduction, joint optimization of inventory and maintenance can be solved sequentally or separatelly, but it produced solution not as optimal as solving simultanously. The next discussion will explain the analysis of model development and result of its model based on case study in Indonesian State Owned Railway Company

A. *Maximum Inventory Level & Maintenance Interval*

The maximum inventory level is the maximum limit value of the spare parts supply status. So, when the inventory status is at a certain time, replenishment is carried out by the company to increase the inventory level to the maximum inventory level. By carrying out a periodic review inventory policy on the supply of critical parts in the locomotive mechanical system can reduce the total inventory amount each year by designing the maximum value of spare parts inventory that has been implemented. Fig. 5 shows a comparison of the value of the maximum inventory level in the actual conditions and proposed conditions and Fig. 6 shows a comparison of the value of the maintenance intervals in the actual conditions and proposed conditions.

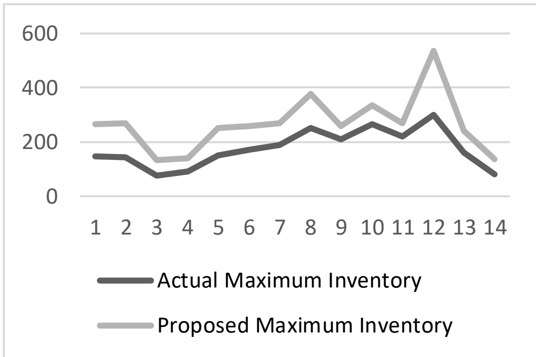

Fig. 5 Comparison Chart of Actual S and Proposed S

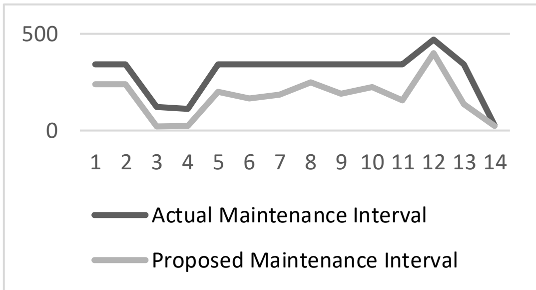

Fig. 6 Comparison Chart of Actual T and Proposed T

B. *Total Inventory Cost & Total Maintenance Cost*

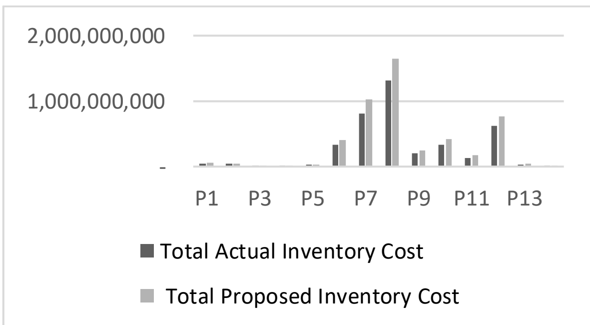

Fig. 7 Comparison of Actual and Proposed Inventory Costs

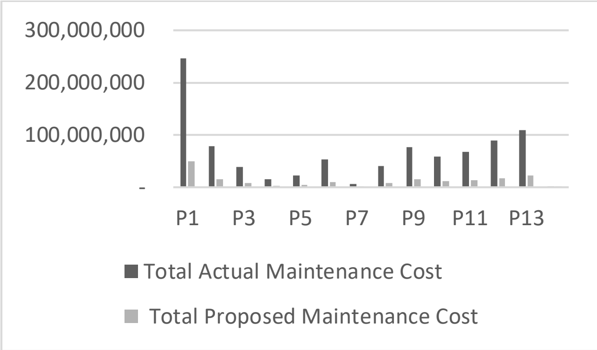

Fig. 8 Comparison of Actual and Proposed Inventory Costs

C. *Total System Cost*

In this section, total system cost was compared between actual and proposed. In accordance with model development of inventory and maintenance, it is proposed to minimize the total system cost by changing the decision variable, namely the maximum amount of critical spare parts inventory and maintenance intervals. In carrying out the settlement process by using the proposed model namely the model with the PSO algorithm approach. In the evaluation process each particle has velocity or velocity to change following particles that have a better solution. In this study using the PSO algorithm with the same speed of each particle. If examined further, basically a more advanced PSO algorithm has different particle speeds. The actual iteration termination criteria depends on whether the iteration has gotten steady state or can still be optimized again, in this study using 3000 iterations because there is a further iteration there is no decrease in the total cost of the system. Fig. 9 is shown PSO algorithm output result based on this research.

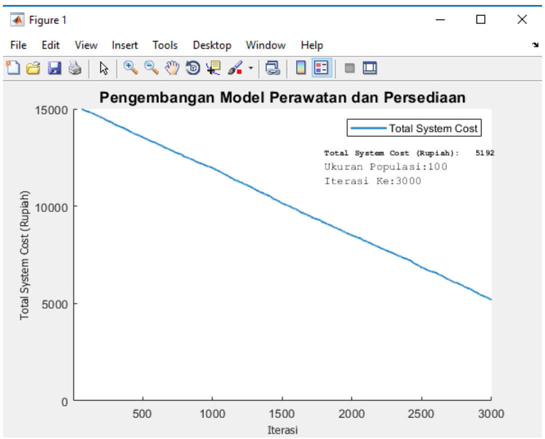

Fig. 9 PSO Algorithm Output Result

The PSO algorithm uses particles that are randomized by the algorithm. In this study, particles that were randomized were the maximum amount of inventory (S) and maintenance interval (T). In the randomization process, data is generated as much as 100 data (population) which are generated and evaluated whether the solution is a better solution or vice versa to produce sub optimal solutions. Fig. 10 shown comparison between actual and proposed total system cost.

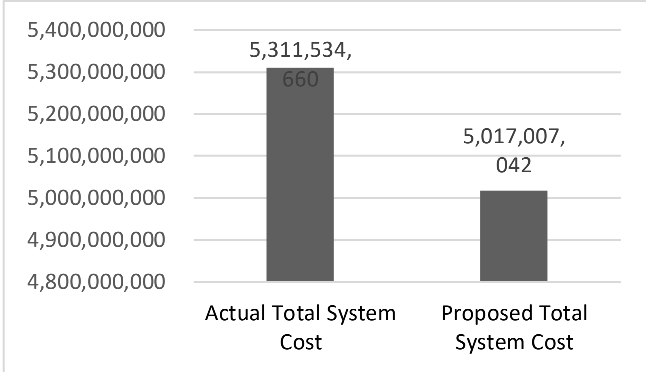

Fig. 10 Comparison of Actual and Proposed Total System Cost

Based on proposed inventory and maintenance model for critical parts by considering the failure rate, deterioration rate, and imperfect maintenance to minimize the total systemcost resulting in a decrease of 5.5% percent or Rp. 294,527,619 from the initial condition of Rp 5,311,534,660, and the proposed condition was Rp. 5,017,007,042.

V. CONCLUSION

This research produces more optimal solution by solving problem simultanously than separately and sequentally. This research is developing the integration model of inventory and maintenance on locomotive spare parts by considering failure rate, deterioration rate and imperfect maintenance. Based on inventory calculations and maintenance intervals for critical sapre parts by considering the failure rate, deterioration rate, and imperfect maintenance to minimize the total cost of the system resulting in a decrease of 5.5% percent or Rp. 294,527,619 from the initial condition of Rp 5,311,534,660, and the proposed condition was Rp. 5,017,007,042.

Based on integrated model development of inventory and maintnance, it can be known that if the preventive maintenance interval gets smaller, then the maximum amount of inventory increases due to more frequent checks and replacements. But this condition has an impact on the decline in corrective costs and downtime costs. In addition to other conditions, if the level of deterioration increases, the optimal maximum number of inventories increases and the treatment interval decreases, while the opposite condition if the deterioration rate decreases, then the optimal maximum number of inventories decreases and maintenance intervals increase.

ACKNOWLEDGMENT

This research was supported by Faculty of Industrial and System Engineering, Telkom University. We also thank our colleagues from Indonesian State Owned Enterprises, especially for corporate university, facilities and infrastructure unit of related company who provided insight and expertise that greatly assisted this research. We are also immensely grateful to all lecturers for their comments on final version of the manuscript.

REFERENCES

[1] A. Van Horenbeek, “Joint maintenance and inventory optimization systems: A review,” *Int. J. Prod. Econ.*, vol. 143, no. 2, pp. 499–508, 2013.

[2] P. S. Muttaqin, “Joint Optimization of Inventory and Preventive Maintenance : Systematic Literature Review and Research Agenda,” *Int. Conf. Ind. Eng. Appl.*, 2018.

[3] M. A. Ilgin, “Graduate School Of Natural And Applied Sciences Joint Optimization Of Spare Parts Inventory And Maintenance Policies By Joint Optimization Of Spare Parts Inventory And Maintenance Policies,” 2006.

[4] J. Cai, Y. Yin, L. Zhang, and X. Chen, “Joint optimization of preventive maintenance and spare parts inventory with appointment policy,” *Math. Probl. Eng.*, vol. 2017, 2017.

[5] J. Sheng and D. Prescott, “Optimising spare parts provision and inspection intervals for an aircraft fleet undergoing cannibalisation,” *Saf. Reliab.*, vol. 36, no. 2, pp. 88–105, 2016.

[6] E. T. S. Bjarnason and S. Taghipour, “Periodic inspection frequency and inventory policies for a k-out-of-n system,” *IIE Trans. (Institute Ind. Eng.*, vol. 48, no. 7, pp. 638–650, 2016.

[7] Y. Jiang, M. Chen, and D. Zhou, “Joint optimization of preventive maintenance and inventory policies for multi-unit systems subject to deteriorating spare part inventory,” *J. Manuf. Syst.*, vol. 35, pp. 191–205, 2015.