A Review on Joint Optimization of Maintenance with Production Planning and Spare Part Inventory Management

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Abstract. In maintenance system, the increasing complexity of the manufacturing system and the joint optimization of maintenance is catching the attention of researchers. Therefore, the aim of the paper is to review the literatures on joint optimization of maintenance with other interrelated functions in the manufacturing system. The classification is made based on the type of decision variables, which are production planning (production scheduling, lot sizing and buffer) and spare part inventory management. The relationships and dependencies are explain in the discussion to show the significance of the integrated model. Most studies considered two functions in their integrated model, which is either maintenance policy with production planning or maintenance policy with spare part management. It can be observe that research on optimization of more than two functions is still new and yet to be explore. Moreover, most researches focused at the decision-making phase without extensive discussion in various functions that might involve. The objective function which is the cost is also presented in the paper. The objective function is categorized into two criteria: maintenance related cost and also inventory and spare part related cost.

1. Introduction

Nowadays, the role of maintenance seems to be more vital than ever due to the increase of automation and mechanization in the industry. Companies are also focusing on being highly flexible but at the same time optimizing their speed, performance and quality. As the output of the maintenance system is in service form, therefore this function should be integrated with all other departments in the organization to ensure a world-class performance. For large scale enterprise, maintenance cost may consume up to 40% of the total operating budget [1-3]. The main function of maintenance is to preserve the ability of the asset to continue performing with minimal failure [1]. Therefore, lack of maintenance to the asset may cause disaster and losses in the plant.

A well-engineered maintenance management is one of the keys for the organization to achieve their competitive strength in the global market. Well-performed maintenance helps to achieve lowest total life-cycle cost of an asset and hence leads to the reduction of long-term cost and hazard level [1]. Maintenance minimizes the possibility of downtime which creates losses due to the cost of idle production, penalty of late deliveries, cost of overtime to complete the order and lost sales [4]. The new paradigm of business that is focusing on continuous improvement on their process, the advancement in Internet of Things (IoT), rapidly changing technology in the 21st century and the transition into Industry 4.0 force the maintenance to improve so that all the functions are on the same pace. The maintenance planning should not be conducted independently as old practice. Integration
with other functions is advisable for risk and cost minimization as well as performance optimization [1][5].

There are factors that are closely related to maintenance engineering which include scheduling, buffer, inventory, routing, spare part and lastly lot sizing. All these factors can be categorized into two main functions which are production and spare part inventory. Production, spare part inventory and maintenance are interrelated functions although in the past they were treated independently. All these functions contribute significantly to the total operating budget, profit and losses of the organization. Production produces output as demanded and therefore contributes to the manufacturing cost and profit of the organization. Another equally important function which is spare part inventory relates to the inventory storage cost and shortage cost. Subsequently, the significance of maintenance to the financials of the organization was proven by the study by Chan et al [6]. According to the author, maintenance cost is about 15% to 30% of total manufacturing cost [6]. The optimization of only one aspect does not mean the lowest cost and best performance for the whole system [5][7][8]. Unilateral planning may end up higher cost and resources to sustain over-assumed system [9].

Collaboration between departments is increasingly essential. As consequence, joint optimization of more than one function has witnessed a considerable growth in these few years. In the review paper by Ruschel et al. [8] on the topic of industrial maintenance decision making, literature relate to joint optimization has a considerable percentage among 16 applications area. There are a few papers that included quality control in their integrated model. The examples are the studies done by Bouslah et al.[10-12], Guo et al. [13] and Fakher et al. [14]. All of the mentioned authors joint optimized quality control together with production planning and maintenance. Their purpose is to create a feedback system that enables the optimization of maintenance level and period with the result of quality control. This function is not included in the paper as the quality control is not the decision variable in the research. The quality control is integrated to determine the optimal planning of maintenance and production.

Considering the potential of joint optimization of maintenance in the future, a review was done on the joint optimization of maintenance with production planning or spare part inventory management. A general overview of the past researches on this topic, a brief illustration on the maintenance strategies and the objective function will be reviewed thoroughly in the paper. This analysis aims to provide an in-depth understanding of the importance of integrating optimization of maintenance with production planning including the production scheduling, lot sizing and the buffer or spare part inventory management. This review focuses on past researches that give the outcome of joint optimized solution on more than one function whether by two stages or simultaneously.

The scope is limited to papers that include costs as the objective function which include inventory cost and maintenance cost. Although some researches might use downtime, environmental impact, service level or safety as their objective function, total cost has the highest popularity among the researchers. Certainly, we cannot doubt that cost minimization is the common goal for all the organizations. They are striving to produce good products with the least resources and waste to gain more competitive advantage than their competitors. Hence, it is crucial to propose the cost model that is able to screen the real cash flow in the industry. In the paper, a comprehensive review of cost elements in the cost model is provided as a guideline for replication. The paper is structured as following: type of maintenance strategy is presented in Section 2; joint optimization of maintenance with production planning is illustrated in Section 3, a discussion of joint optimization of maintenance with spare part inventory is in Section 4; Section 5 is the discussion of objective function which is the total cost and finally the conclusion of the review is in Section 6.

2. Maintenance Strategy
The maintenance strategies can be categorized into three types which include corrective/ breakdown maintenance (CM), preventive maintenance (PM) and conditional-based maintenance (CBM). The three strategies have their benefits and limitations. Although they have a different concept, they
involve similar procedure which is the inspection of the status of machines and replacement or repair of the failed part [5].

Corrective Maintenance (CM) is the maintenance task conducted when the asset degrades until it fails unexpectedly. CM is an unscheduled maintenance task and thus requires highest priority. The replacement or repair work should be done as soon as possible as the machine failure may interfere the production planning. For this reason, CM is known as firefighting approach [7][15][16]. CM tasks may consist of fail-repair, salvage, rebuild, overhaul and servicing [7]. CM is an important factor in the performance of maintenance as CM consumed more effort from the organization [7]. This strategy is suitable to be used for only some cases. For example, when the hazard rate is constant, the failure does not bring serious effect or losses and the breakdown equipment has low priority among other machines. The limitation of CM is that it has a high possibility to halt the whole production especially when the shortage of maintenance resources including spare parts and technician occur [5].

Preventive Maintenance (PM) is then introduced to minimize the drawback of stochastic breakdown. PM is the planned maintenance task in which the task is conducted on a scheduled basis and interval. The planning of PM may be based on the recommendations of equipment manufacturers and the failure distribution data of the machines [17-18]. The tasks that will be conducted during PM are inspection servicing, calibration, testing, alignment, adjustment and installation [7]. PM brings benefits by increasing the system availability, balancing the workload, reducing the overtime, increasing the revenue, ensuring stable product quality and improving safety. However, the implementation of PM may not be cost effective if the planning is not optimal. PM has disadvantages as well. The spare part consumption is higher and thus increase in cost. The equipment may be exposed to possible damage between the interval of PM. Although PM may reduce the possibility of machine failure, there is still the possibility of machine breakdown unexpectedly. Therefore, the role of CM cannot be neglected as well during stochastic machine breakdown [7].

For traditional concept for PM, the machine is assumed to be as good as new after the maintenance. However, in the real case, the state of the machine is between as good as new and as bad as old after PM. This concept is called imperfect maintenance. It assumes that the failure rate decreases after each PM. This concept had been used by many authors so that the proposed model will be more realistic and relevant to the industry [10][13][19-20].

Conditional-based maintenance (CBM) is another more advanced maintenance strategy had grown its popularity among the industry nowadays. Many authors used CBM in their studies [21-24]. For CBM, the maintenance task is conducted based on the comparison of the condition of the assets to the threshold. Therefore, diagnostic software, sensors or cameras are required to monitor routinely the condition of the machine and then compare with the pre-set threshold. The variables that are collected include the machines’ vibration, temperature, oil analysis, pressure and so on [17]. CBM is suitable to manage critical wear [25]. This maintenance strategy brings maintenance closer to the production. However, its drawbacks are that high skill and high technology equipment are needed. CBM can be planned but cannot be scheduled [1]. For the current trend, CBM has the highest interest from the researchers. 40% of the literature reviewed by Ruschel et al. [7] are on CBM. In this case, the need for real-time monitoring technologies is increasingly vital. Whereas for preventive maintenance, it has 23% of all the reviewed literature which is the second highest from the maintenance strategies [8].

3. Joint Optimization of Maintenance with Production Planning
Production and maintenance planning are among the most common and significant problems faced in the manufacturing industry [26]. In the past, production and maintenance planning were treated separately and independently in the production line. Most of the past studies on scheduling assumed the machine never breakdown [5], [27]. There are plenty of researchers that studied the maintenance planning method. Review done by Ernnie et al. had provided comprehensive information on preventive maintenance planning and the methods used in the industry [18]. Ruschel et al. [8] also presented a review paper about industrial maintenance decision-making, the proposed models and the application of methods and tools.
However, in reality, the maintenance activities may interfere with the production output and performance. The delay of maintenance may cause the stoppage of the line and lead to decrease in availability and scheduling disorder. Meanwhile, the duration of the maintenance task will affect the system availability. Most of the time, maintenance department and production department have different objective and therefore cause conflicts. For example, the production manager does not willing to stop the production for planned maintenance whereas the maintenance manager would prefer to increase the frequency of maintenance to reduce the breakdown of machines. The machine is unavailable during the implementation of scheduled PM task or unscheduled CM task [5][26][28-29]. Due to the interdependence between them, the joint optimization of production and maintenance has become a vital issue. Recently, there is growing interest in optimizing maintenance policy together with production planning. The scope of production planning is limited in the integrated model that include production scheduling, lot sizing and buffer.

3.1. Maintenance with Production Scheduling

There are a few researchers try to integrate the planning and optimization of maintenance and production scheduling. In 1996, Asharyeri et al.[30] had developed a mixed-integer linear programming model to optimize the preventive maintenance and scheduling of the production job in order to minimize the production cost and maintenance cost. Cassady and Kutanoglu [31], Wang and Liu [32], Benmansour et al. [27] and Liu et al. [28] presented integrated maintenance and production schedule for a single machine system. The objective of the study of Cassady and Kutanoglu [31] is to optimize the Preventive Maintenance action and job sequence with the hope to minimize the total weighted expected completion time. Wang and Liu [32] had proposed an integrated optimization model for production scheduling and preventive maintenance with its time to failure subject to a Weibull probability distribution. Benmansour et al. [27] aimed to determine the optimal period to perform preventive maintenance and the sequence of the job to minimize the cost. This is the first study that considers tardiness cost problem in their optimization study. In the model proposed by Liu et al. [28], dummy age (system existing age) of the machine is introduced to show the effect of the maintenance action. Dummy age decreases when implementing a maintenance task. This integrated model beside solving job scheduling and maintenance planning problem, resource planning had been determined simultaneously as well [28].

Joint optimization of maintenance and production scheduling for a multi-machine system is more complex than a single machine system. Optimal maintenance policy for a single machine may not be optimal for the multi-machine system. More constraints must be considered in the model. The study of Xiao et al. [26] had optimized the production scheduling and preventive maintenance in a series system to minimize total cost including production cost, preventive maintenance cost, minimal repair cost for unexpected failures and tardiness cost. The decision variables to be determined are the optimal group preventive maintenance interval for machines and the assignment of the PM task which is the starting and ending time of the maintenance activities. However, the assumption causes the imperfection of the model. The author assumed the machine is as-good-as new after the maintenance [26]. On the other hand, Portioli-Staudacher and Tantardini [29] assumed that the whole production line will stop during maintenance. Hence, their proposed mathematical model is able to model the multi-machine system as a single machine with a single production rate. Their mathematical model joint planned the production and preventive maintenance activities that can be used for rescheduling purpose. Their objectives are to minimize production cost, maintenance cost, inventory carrying cost, workforce cost and rescheduling cost [29].

3.2. Maintenance with Lot Sizing

Traditionally, maintenance and lot sizing are planned separately as they are related to different cost elements. The optimization of the maintenance schedule is to reduce the cost of maintenance, downtime and failure whereas the optimization of production lot size is closely related to the cost of inventory, setup and lost sales. In fact, the two parameters are closely related too. The failure may
occur in the middle of production of a lot and so the integrated model of maintenance and lot sizing is necessary as well. The failure of the machine causes stoppage which then leads to lost sales. Furthermore, to minimize the interruption to the production, it is advisable that the maintenance task is conducted during the idle time of the machine or after the production of a complete lot [22].

There are papers found in the literature that jointly optimized lot sizing and maintenance planning. Bergeron et al. [33] had conducted a study to joint optimize lot-sizing and preventive maintenance periodicity of each machine in a serial production line to minimize the sum of production and maintenance cost. The machines are separated by the buffers and the optimal buffer size will be considered in the model as well. The optimization method used is the combination of Tabu Search and Scatter Search algorithms [33]. The study of Nourelfath et al. [20] integrated production, maintenance and quality in their model in order to minimize the total cost, but at the same time complete the demand of all products. They considered a multi-period multi-product capacitated lot sizing problem rather than the EPQ models which only apply to single inventory item [20].

In 2015, Jafari and Makis [23] joint optimized economic manufacturing quantity (EMQ) and preventive maintenance for a production facility. Their objective is to minimize the long-run expected average cost per unit time which include inspection cost, lost production cost, inventory holding cost, preventive maintenance cost, corrective maintenance cost and setup cost. The optimal decision variables to be determined are production lot size and preventive maintenance level [23]. Beheshti-Fakher et al. [34] also joint optimized maintenance plan, lot sizing and quality decision for a single machine producing multiproduct. Their study determined the optimal PM level to be performed at the beginning of each period and the optimal lot size to be processed in each period [34]. In 2016, Bouslah et al. [11] integrated production, preventive maintenance and quality control for a stochastic production system while meeting a predefined restriction on the average outgoing quality limit (AOQL). The study determined the optimal production lot size, inventory threshold, the sampling plan parameters and the overhaul threshold [11].

In the study conducted by Peng and van Houtum [22], the production lot size was optimized by taking the CBM activities into account to minimize the average long-run cost rate. The proposed model used the renewal theory. Control limit policy was used to determine the time to conduct the predictive maintenance and they assumed that maintenance tasks are conducted during machine idle state. The purpose is to reduce the interruption to the production plan [22]. Guo et al. [21] also conducted a study on optimization of production lot size and CBM for a multi-component production system to minimize the total cost including preventive maintenance cost, corrective maintenance cost, setup cost, inspection cost inventory holding cost and the shortage cost. The objective of the study is to optimize production lot size and preventive maintenance threshold by using the coupling model and genetic algorithm [21].

In another paper published by Guo et al. [13], the model proposed integrated the production lot sizing, quality control and maintenance planning. The maintenance strategy used for this production line is condition-based maintenance. The decision variables to be optimized in the study are lot size, inventory threshold, preventive maintenance and overhaul thresholds. Inspection is carried out after every production run. Maintenance is implemented if detected degradation level exceeds the threshold. The paper explained the influence of parameters on system performance. The summary of the influence of parameters to the decision variables is summarized as Table 1. The parameters included in the test are production setup cost, PM cost, CM cost, overhaul cost, inventory holding cost, rejection cost of defective item and shortage cost. The author studied the effect of the increment of the parameters on the optimal lot size, inventory threshold, overhaul threshold and PM threshold [13].
Table 1. Relationship of the parameters on decision variables

| Parameter                              | Optimal lot size | Optimal inventory threshold | Optimal overhaul threshold | Optimal PM threshold |
|----------------------------------------|------------------|-----------------------------|----------------------------|----------------------|
| Production setup cost increase         | Increase         | Increase                    | Decrease                   | Decrease             |
| PM cost increase                       | Decrease         | Increase                    | Decrease                   | Increase             |
| CM cost increase                       | Decrease         | Decrease                    | Decrease                   | Decrease             |
| Overhaul cost increase                 | Decrease         | -                           | Increase                   | Decrease             |
| Inventory holding cost increase        | Decrease         | Decrease                    | Decrease                   | Increase             |
| Rejection cost of a defective item     | Decrease         | Decrease                    | Decrease                   | Increase             |
| Shortage Cost increase                 | Decrease         | Increase                    | Decrease                   | Decrease             |

3.3. Maintenance with Buffer

The significance of the buffer cannot be ignored also in maintenance planning. The effect of stoppage due to failure and maintenance can be alleviated with buffers built between machines. Therefore, the buffer level and buffer inventory holding cost are closely related to the maintenance frequency. To study the relationship of maintenance and buffer, D.Meller [35] and S.Kim [36] conducted a study on the impact of preventive maintenance on system cost and buffer size. Fitouhi et al. [37] also developed a methodology to analyze the tradeoff between preventive maintenance and buffer to the system performance.

Some researches had been done on the joint optimization of maintenance and buffer. Ribeiro et al. [38] jointly optimized the maintenance of a capacity-constrained resourced, its feed machine and inlet buffer size with a mixed integer linear programming model. The study of Bergeron et al. [33] as mentioned in section 3.2 also considered optimal buffer sizing in the proposed model. Buffer sizing was optimized to reduce the blockage and starvation of machines on the production line [33]. Gan et al. [35] focused on the joint optimization for maintenance, buffer and spare parts for a production system with genetic algorithm. The buffer inventory affects the inventory holding cost. In order to determine the significance of optimizing four variables related to maintenance, buffer and spare parts simultaneously, comparisons were made among four-variable optimization, three-variable optimization and two-variable optimization. The optimization results are different. When only two of them are optimized, the decision on the third variable may be improper, therefore leads to undesired optimization result [35].

4. Joint Optimization of Maintenance with Spare Part Inventory Management

Joint optimization of maintenance and spare part or inventory management is also an interesting topic for research. The performance of maintenance has a high dependency on the availability of the spare parts. The shortage of spare parts leads to delay of maintenance work, thus prolong the downtime of the line. In contrast, excessive spare parts may end up with high holding cost. Hence, an optimum level of spare part is necessary to ensure the smoothness of the maintenance task and minimal inventory cost [5][39].

For past studies in old days, the planning and optimization of spare parts and maintenance activities were done separately also. For spare part inventory management, it relies on past spare part demands rather than the maintenance planning [24][39][40]. The researchers assumed 100% spare parts’ availability during the maintenance task. To fulfill this assumption, the spare parts should be highly standardized for easy procurement, or low cost so that large quantities can be stored to avoid stock-out [41]. However, this is not applicable in the real case as many of the parts are highly customized. Also, the ordering of spare parts from suppliers often requires certain lead time [42]. The oversimplified assumptions will definitely require high inventory holding cost to store extra spare parts.

Therefore, the optimization of maintenance activity should be done simultaneously with spare part inventory management for timely supply of resources. For this topic, Adrian et al. [9] had done a
review paper on joint optimization of inventory and maintenance that include costs. A framework was proposed in this paper to classify all characteristics which are important [9]. The two inventory review policies include continuous review policy and periodically review policy. For continuous review policy, the inventory level is checked continuously and the order is made when certain condition occurs. The two most common policies are (s, S) and (s, Q) policy. Whereas when the inventory is reviewed periodically, the order is made based on the forecast demand at the beginning of each cycle. For example, (R, S) policy. From the review paper, the first policy is more common as 15 out of 23 papers applied continuous review policy in their studies. Please refer to the review paper for more information on inventory review policy [9].

The study on this topic is developing rapidly. The recent studies include the work presented by Zahedi-Hosseini [43] which is also the first study on this topic that involves a parallel system. The planned maintenance inspection interval, T, review period R, and the order-up-to level S of the periodic review inventory replenishment policy were optimized. The researchers utilized the ProModel Discrete Event Simulation package and the optimization tool SimRunner to determine the optimum policy [43]. Olde Keizer [20], Jiang [41] and Gan [32] joint optimized the maintenance and inventory control of spare parts for a multi-component system because in real case the systems contain multiple components. Optimal maintenance and spare part inventory management for a single component is not always optimal for a multi-component system [24][35][44]. Gan's work is the first optimization work that considers maintenance, spare part inventory and buffer. Four control variables include the preventive maintenance age, the spare part arrival time, buffer size, and the initiating time of buffer accumulation was optimized to obtain minimal long-term expected cost [32].

Panagiotiduo [45] on the other hand derived optimal inspection interval and provided sufficient spare parts to support both corrective and preventive maintenance task in order to get the minimal expected total maintenance and inventory cost per time unit. Mjirda [46], Kader [47] and Wang [48] conducted joint optimization for preventive maintenance and spare parts inventory problem. Mjirda [46] determined an optimal maintenance schedule with taking account the inventory management of spare parts whereas Kader [47] determined the optimal maintenance plan and order quantity of spare parts simultaneously to minimize the global cost and carbon footprint. Wang [48] on the other hand optimized the order interval, PM interval and order quantity.

In 2011, Wang [39] had also conducted a study to optimize three decision variables which are ordering quantity and interval and also inspection interval using the Delay-Time concept. Same to Zahedi-Hosseini [43] and Wang [48] who also adopt Delay-time concept in their studies. Meanwhile, Olde [24] and Zhang [49] conducted studies that consider condition-based maintenance. Olde saved significantly from optimizing both maintenance decisions and the timing of ordering spare parts [24].

5. Objective Function

For most past studies done, the most common objective of joint optimizing for maintenance and other function is the minimization of cost [50]. All the decision made related to the line from production planning to maintenance policy and spare part management will affect the total operating budget. Hence, there is a need to seek for the balance between these functions for a minimal operational budget. Gan et al. [35] explained about the relationships between maintenance, spare part and buffer and their effect to the system cost which is the sum of inventory holding cost, spare part ordering cost, maintenance cost and shortage cost. The figure provided in the paper can be a guideline to illustrate the relationship of the functions to the total cost. The relationship of cost elements with the maintenance planning was also explained in the paper by Bouslah [12]. In Levitt’s book [51], the author mentioned the cost area that can be decreased with good maintenance practices are. The mentioned cost element in his book can also be included as the cost model so that the model will be more realistic [51].

The cost elements chosen are dependent on the parameters involved in the joint optimization with maintenance. In this paper, the cost factors are categorized into two groups which are maintenance related cost, and inventory related cost. These two categories are the most commonly included in the
proposed cost model. The maintenance-related cost includes all the cost element for the input to the maintenance task and the losses due to the failure in repairing the breakdown asset immediately whereas the inventory related cost is the cost of stocking and purchasing the spare part for maintenance and the production materials. Some author also includes the production related costs in their cost model. However, most of them do not describe in detail the cost elements involved in this category. A variable rate of production cost was added into the model without giving further explanation. Hence, this category is not included in the discussion.

5.1. Maintenance related cost

Most of the constructed cost model will consider a fixed value for corrective maintenance or preventive maintenance and cost of sampling or inspection. Some may include also the cost of labour, cost of downtime and material cost. Further information related to the cost of spare part will be further illustrated in the next section. The two hidden costs that should be considered when comparing the maintenance policies are the cost of downtime and cost of emergency repair. The cost of downtime is usually the highest core cost area. Its calculations are difficult as they are not definable cost and their reason is sometimes confusing. Meanwhile, the emergency action to restore the breakdown unit leads to disruption to the production, hence reducing the output of the production. These losses should also be included in the model [1].

The model is not able to represent the total cost of the maintenance system without considering the penalty cost. In the cost model by Xiao et al. [26], Benmansour et al. [27], Liu et al. [28], Pandey et al. [52], Dellagi et al. [53] and Fakher et al. [14], they included penalty cost associated with schedule delay or some known as tardiness cost and backorder cost. Penalty cost is incurred only when the order is not completed on time. This is because the decision on maintenance policy may affect the production scheduling[14][26-28][52-53]. Pandey et al.’ [52] model also included the cost of rejection which is caused by the performance degradation of the machine. The poor quality of the products produced by such machine will end up with rejected item. This cost element varies depending on the type of production system and it may be criteria for maintenance planning. If the cost of rejection is too high, the cost of corrective maintenance is higher than the cost of preventive maintenance. Therefore, the period of preventive maintenance should be reduced [52].

The other rare cost elements that are included in the cost model are as follows. Restoration cost which is a function of the detection delay. Separation cost is the cost to separate conforming and nonconforming unit [14]. In Hennequin and Ramirez Restrepo ‘s [54] cost model, they included hardship cost which is related to losses due to machine ergonomics and accident in the line.

5.2. Inventory related cost

There are two types of inventory that are considered in the cost model which are the production inventories and maintenance spare part inventory. The production inventory consists of raw material, subcomponents and the finished product that have not been shipped. Whereas for the maintenance spare part inventory, it relates to the spare part needed for repairing and the scheduling of maintenance task. Both serve the different departments and thus should be separated in inventory management. To calculate the cost of inventory, it is very significant to include the factor of investment cost, expenses of warehousing, taxes, insurance, labour cost, cost of deterioration, shrinkage, obsolescence and return. The inventory cost is usually unique for each operation [51].

The cost of maintenance spare part inventory is included in most of the proposed cost model especially in the joint optimization model related to spare part management. The maintenance material is considered a significant cost element in total maintenance cost. It’s percentage is between 40% to 50% in the usual US industry [7]. Beside the cost of the spare part itself, the spare part holding cost is the most common inventory related cost included in the cost model. This cost element appeared in the researches done by Gan et al. [35], Wang [39], Jiang et al. [44], Panagiotidou [45], Mjirda et al. [46], Wang [48] and lastly Zhang and Zeng [49]. In most of the paper, they set a fixed rate for holding cost
per unit time. The assumption made is all the spare part will be using the same pre-determined holding cost rate [35][39][44-46][48-49].

Some researchers considered the ordering cost for spare part in their cost model as well. This cost element can be found in proposed cost model by Gan et al. [35], Wang [39], Jiang et al. [44], Wang [48] and also Zhang and Zeng [49]. Subsequently, the insufficient spare part affects the performance of the maintenance which leads to losses. This cost element attracts the attention of researchers recently. The spare part shortage is incurred when the consumption rate is more than replenishment of spare part inventory, causing the spare part shortage and thus delay the maintenance task. This cost element was included in the studies by Gan et al. [35], Jiang et al. [44], Panagiotidou [45] and Mjirda et al. [46].

In the studies that joint optimized maintenance with production planning including scheduling, lot sizing and buffer, the holding cost for inventory is added into the cost model. The examples are the studies done by Ben-Daya and Noman [19], Bouslah et al. [10], Cheng et al. [21], Peng and Van Houtum [22], Jafari and Makis[23][55], Gan et al. [35], Suliman and Jawad [56]. In the cost model proposed by Gan et al. [35] also, shortage cost was included. This cost element is incurred when the precedence machine breakdown and the buffer is exhausted. Restoration rate is slower than the consumption rate, end up the possibility of stoppage of the whole line [35]. For illustration, this cost element was also discovered in researches by Jafari and Makis [55] and also Suliman and Jawad [56].

Some researches feel that adding in backlog cost is significant. Bouslah et al are among them as backlog cost can be found in their three papers [10-12]. Backlog cost occurs when the customers need to wait until the complete batch of demand is completed. To minimize the total cost, the organizations need to find a balance point between backlog cost and inventory holding cost [57]. The paper by Bouslah et al. in 2013 had given a clear picture on the effect of backlog cost to the safety stock level and optimum lot size [10]. Lastly, the cost of disposing surplus buffer inventory is very rare as this cost element can be found only in the study by Gan et al [35].

5.3. Discussion
From the discussion from section 5.2 and 5.3, it's clear that there is no standard on the cost element that should be included in the cost model for the joint optimization of maintenance. Besides dependent on the parameters for joint optimization, the decision is also on the hand of stakeholders. However, a brief guideline on the common cost element to be included is provided in Table 2 for reference.

| Parameters for Joint optimization with maintenance | Common Cost Element included in the cost model | Other Cost Element included in the cost model (optional and dependent on the stakeholders) |
|---------------------------------------------------|-----------------------------------------------|-------------------------------------------------------------------------------------|
| Production scheduling or job sequencing           | Maintenance Cost (PM and CM), Inspection Cost, Setup Cost, Tardiness Cost or Penalty Cost | Labour Cost, Cost of Lost Sales, Backorder Cost, inventory holding cost              |
| Lot Sizing, Buffer and Spare Part Inventory       | Maintenance Cost (PM and CM), Inspection Cost, Setup Cost, Downtime Cost, Spare Part Cost, Inventory Holding Cost, Spare part Ordering Cost, Spare part Shortage cost, | Labour Cost, Cost of Rejection, Backlog Cost, Inventory Holding Cost                 |

Most of the literatures discussed about preventive maintenance policies. For PM, the concept of imperfect maintenance is gaining the interest from the researchers. Conditional based maintenance is also comparatively popular in the past research. The maintenance-related decision variables that are usually found in the past studies are scheduling of maintenance task, maintenance period, maintenance level and maintenance threshold. Similarly, the most common cost elements that are included in the cost model are the PM or CBM cost, spare part cost, labour cost and setup cost (appear occasionally).
The other cost elements are included depending on the objective and the scope of the study. However, it is encouraged that the losses and penalty due to faulty planning are added into the cost model so that the model is as convincing as possible. For example, shortage cost of the spare part, cost of downtime, penalty cost for incomplete or late order and cost of lost sales. A few researches had added the penalty cost element into their model. Cost of rejection, separation cost, hardship cost, surplus cost and backlog cost are comparatively less frequent in the past papers. The report of the state of art research in joint optimization for maintenance provides direction for future research. The review paper acts as a guideline to help the industries in improving their integrated model. Close collaboration between departments brings down risk in decision making and improves communication within the organization. The joint optimization concept increases the flexibility of the organization by saving the time in their planning, besides result promising. This effort is definitely stepping stone for them to achieve world-class OEE. Although there are attempts done that consider more than one functions out of three discussed functions, more effort is needed. From the review conducted, it was found that researches on joint optimization of multi-unit system is limited. Most of the paper which study multi-unit system treated the whole system as single-unit system due to the assumption made.

As reviewed by Van Horenbeek [8], most publications on joint optimization of maintenance are on the tactical level of decision making [9]. The researches on the implementation of the selected strategies are infrequent, thus raising the doubt to the feasibility of the decision made. Future research on this area is urged to validate the chosen solution. Therefore, researches must make effort to bridge experimentation model or project with real implementation to validate the success of decision made and the proposed methodology. Lastly, for the objective function, there is still lack of clear guideline on the cost element that should be included in the cost model, end up we have lack of cost model that consider the penalty cost and losses due to faulty planning. These hidden costs are advisable to be included in the model although the maintenance does not directly relate to the penalty cost of losses sales and shortage cost.

6. Conclusion
This paper presented the significance of joint optimization of maintenance policy with production planning (production scheduling, lot sizing and buffer) and spare part management. Their relationship and effect to the total cost were explained based on review of various publications and literatures in this research area. Many publications had explored the integrated model of maintenance with production planning and maintenance with spare part. However, there are limited research that joint optimized more than two functions in the model. Therefore, this area shows high potential due to the need for more realistic model to replicate complex manufacturing system. The review shows that maintenance, production and spare part are three interdependent functions. Neglecting any one of them may end up extra operating budget to sustain the system with oversimplified assumption.

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