An Investigation of Optimum Safety Stock Level for Maintenance, Reliability and Operation Materials based on Criticality of Material and Equipment

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***Abstract*— This paper presents a study to determine a safety stock level calculation for Maintenance, Reliability and Operation (MRO) materials in oil and gas industries. The challenge to set a safety stock for MRO materials is uncertainty of demand and lead time especially in industry where the operation plant is far away from materials manufacturer. Many models currently used to calculate the safety stock is independent between inventory control as service provider and maintenance as service receiver. Current models of safety stock are referred to equipment reliability or stock out situation to measure the effectiveness of the models. In this paper, studied the correlation between maintenance activities and inventory control strategy to provide acceptable service level thru combined equipment and material criticality with optimum inventory safety stock level by linked the acceptable downtime of equipment with lead time of ordering materials. Based on this study and comparison of the proposal with available models related to equipment and stock out focus, the proposal result is between current models of safety stock level calculation result .**

Keywords— Safety Stock Level; Criticality of Equipment and Materials; Lead Time; Downtime; Mean Time between Failure

1. Introduction

Material or spare parts are very significant to ensure the reliability and production process in production plant. To ensure the material availability to serve the plant requirement when required is required to have stock near the production plant. The concerns for stocking materials are uncertainty of requirement in terms of quantity or time and other concern is the uncertainty of order lead time because of many considerations during order and delivery process from internal organization or external organization.

There are different focus area between service provider and service receiver related to stocking purpose. Maintenance as service receiver calculate the safety stock level with main concern on the equipment reliability where the purpose of safety stock is to ensure material is available at any time and any quantity when required. In other side, inventory controller as service provider is required to have stock level as minimum as possible. Those contradictive of aim to have stock in inventory continuously become a topic of discussion for both parties. Safety stock model refer to maintenance approach usually proposed high safety stock and with stock out avoidance model rever to deviation of lead time used by inventory controller usually proposed loh safety stock level. Those conditions are generated other issues, for maintenance model intention is the stock will high and potential create over stock in inventory. From inventory control models, the proposed of safety stock level is very less compare with maintenance model due to inventory control only capture the safety stock for deviation of lead time and unexpected requirement.

Lead time is a main factor to divined the level of safety stock, also downtime of equipment need to consider on the calculation of safety stock because of long lead time compare with acceptable downtime is raise the uncertainty to production process and with information of acceptable downtime is help inventory control to manage the delivery process either deliver the spares by faster delivery with higher cost or inventory control could choose the lowest cost with longer delivery time. These considerations are support inventory management to manage more affective of inventory and ordering cost.

2. Literature Review

2.1. Supply Chain and Inventory Management

Supply chain process for MRO materials in the production plant is a connecting activity between internal and external organization. Every activity is linking each other in terms of process, activity and impact. Generally, the supply chain process and activity is involved user department, supply department, finance department and supplier. Figure 1 shows the connection of each section in the supply process of materials.

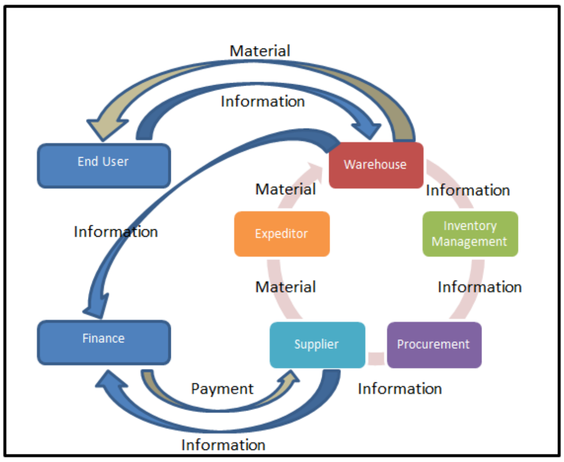

Figure 1. Supply Chain Connection of MRO Spares

Information flow process is information related to request of material (demand) and material flow process is a process of delivery material (supply). Overall process of supply chain is not always even as required, in some condition the process is have uneven condition. Some cases the uneven condition is unpredictable, such as because of plant condition or the situation is beyond the internal organization control. In production industry where the equipment is non-stop operating, leak on the material supply is became serious condition. Because of that reason, in the production plant is required to have materials standby to be used as required.

Inventory is a stock of materials used to facilitate production or to satisfy customer demands [1]. Inventory materials can be segregate based on the function of the materials, Inventory materials for production purpose and inventory materials to ensure the equipment is working in good condition. Inventory related to the production process are raw materials, in process materials and product materials or finished goods. Other kind of inventory material related to the equipment reliability, called as Maintenance, Reliability and Operation (MRO) materials. The purpose of have MRO materials stored in warehouse are

- To mitigate uncertain conditions, uncertain condition mostly because of the supply is not meet with the demand, there is a problem on the delivery process because of the location of supplier and the production plant or the uncertain condition is come from equipment condition itself.
- Economical order, order materials in bulk is have advantage in term of material price or shipment cost. In some cases, material is not sold in individual because of the nature of the material or packaging.

Material stored in warehouse is considered as cost. In many profit organization, they consider inventory is as one of operating cost and this operating cost have direct impact on the company profit. To have low inventory cost is good indicator to the company profit but in other factor is the production or sales lost because of stock out need to be consider. There are three basic of inventory costs, all those costs are associated with carrying or holding cost, ordering cost and shortage cost. [2]. Other author defines inventory cost as inventory costs as holding cost, ordering cost and set up cost. [3] And inventory cost is basic of inventory model is based on the generic cost function, where the cost functions are purchasing Cost, setup Cost, holding Cost, and Shortage Cost. [4].

To ensure replenishment process is align and appropriate is required a systematic process. Material Requirement Planning (MRP) is a computerized inventory control and production planning system [2] to support the replenishment process of materials. In production planning, MRP process initiated from master production schedule, in operation industry MRP process initiated from maintenance schedule either for regular maintenance or for turnaround maintenance. With the advance of the electronic enterprise, the communication between maintenance planning and MRP is lean. Required material for maintenance activities can be direct to inventory section to act based on the given schedule.

2.2. Materials Demand and Maintenance Strategy.

Demand of materials are distinguished between independent demand and dependent demand [5]. Independent demand means the requirement of the material not related to other materials to do a job, dependent demand means the requirement of the materials are directly related to other materials. Demand for MRO materials for maintenance and operation activities could be dependent and independent demand, it is related to the characteristic of that spares or materials and the equipment needs. The demand of the materials is related to Bill of Materials (BOM) and maintenance recommendation from manufacturer.

In terms of maintenance activities, the material demand can be differentiated to four main maintenance activities, Preventive Maintenance, Predictive Maintenance, Corrective Maintenance, and Breakdown Maintenance. Materials for preventive maintenance are predicted materials because of required material for the maintenance activity is identified from the maintenance guidance from manufacturer. Preventive maintenance is a maintenance activitiy when the equipment in operating condition, to maintain the condition of equipment. [6]. The aim of preventive maintenance is to slow down the wear process and to reduce the frequency of occurrence of system failures. Based on the characteristic of this maintenance activities, demand of the materials can be identified before the job performed and mostly the materials for preventive maintenance is independent demand such as lube oil, gasket, etc, no major spare parts change during preventive maintenance. Other author defined predicitive maintenance is a regular activities to monitor the condition of actual equipment condition, operating efficiency, and other indicators of the operating condition of equipment with aim to have require data to ensure the interval between repairs is maximimum and to minimize the un-schedule outgate of the equipment. [7]. Basic activity for the predictive maintenance is a condition monitoring of the equipment, such as vibration monitoring, temperature monitoring, pressure monitoring or alignment monitoring.

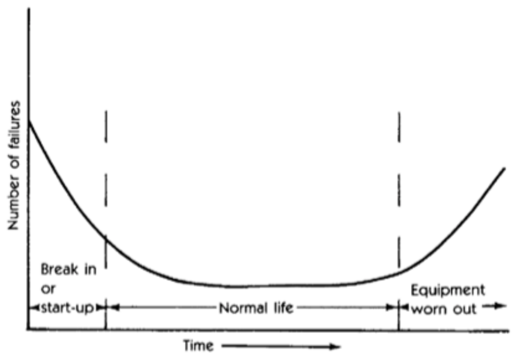

Figure 2. Typical Bathtub Curve
(Source: Mobley 2002)

Bathtub curve as shown in Figure 2 informed corelation between the numbers of failure of the equipment and the service time of the equipment. There is a certain period equipment will worn out, at this point early information from condition monitoring and preventive maintenance is very usefull to maintenance make a decision to what and when maintenance to process a major maintenance process to revert back the operational condition of the equipment to the maximum performance.

Corrective Maintenance continuously follow the recommendation form manufacturer. In general process of corrective maintenance is depend on the working hours of the equipment. After reaching recommended working hours, maintenance required to perform major check of the equipment. Equipment put in down condition and maintenance processed the overall check of the equipment indicate during preventive and predictive maintenance. The corrective maintenance is a maintenance activities to identified and rectify the cause failures for a failed system [8]. In other terms, corrective maintenance is an activity to place the condition of equipment back to normal condition after the equipment failed during normal operation. Corrective maintenance has a specific schedule for corrective maintenance refer to manufacturer recommendation.

In actual condition, equipment always have disruption on the operating process either the disruption come from internal equipment itself or come from external condition. Those unpredictable conditions could be break the operating process of the equipment. The occurrence of equipment breakdown because of unpredictable failure of components and because of gradual wear and tear of the part, which all that unpredicted failure cannot be prevented [9]. Uneven condition or breakdown an equipment has direct impact to overall production process especially for a plant with interconnecting process to produce a product such as oil, gas or petrochemicals.

Refer to above description of material demand and maintenance strategy, there are conditions where materials are required with planning or without planning and correlation between one spare part with others could be dependent or independent spares. All those conditions could be combine in terms of requirement, dependent materials could be required with plan or without plan and similar with independent materials could be required with plan or without plan. Those uncertainty condition create a challenge to strategy of material stocking philosophy where the stocking strategy require to balance between stock cost and potential production loss cost.

2.3. Lead Time and Criticality

Lead time in supply chain management process is processing time start from customer place the order to the material ready for delivery. Lead time for component is the time required to acquire include purchase, produce or assemble time [3]. Many researchers studied and analyze the correlation of lead time with production process in term of efficiency, cost impact on total production cost and loss of opportunities. Uncertainty of lead-time have much influence to have optimum inventory value. [10]. And other author identified one of the risk in the spare part optimization is deviation of supplier delivery which is related to total lead time of production process [11] and the main influence for the safety stock calculation are variation of demand and replenishment time. [12]

In MRO process materials are not always available in shelve, because of the issuance and order processing time or the stock out condition because of un-expected demand for the materials.

Total lead time calculated based on the internal organization process and external organization process. Internal organization process is start from purchase requisition created until purchase order acknowledge by manufacturer or supplier. The next lead time calculation is start from manufacturer or supplier received an order until deliver the material to agreed incoterm when purchase order in place. Many activities need to follow during internal process such as purchase requisition approval process, request for quotation process between purchasing and supplier, commercial negotiation and specification review process. Those process is take times longer if the order process is not direct to manufacturer, order thru supplier will take longer time on the request for quotation stage because of there is other request for quotation process between supplier and manufacturer. Other external process has impact on the total delivery time is delivery process from manufacturer to end user especially the material is ordered overseas. There are few process and condition have impact on the delivery time, such as mode of transportation used for delivering the material, thru sea freight or air freight. Every country has generals and specific standard processes and regulation to handle imported material, especially for dangerous goods such as chemical, gases or material categorized as material could be used to create a weapon. To calculate the stock level parameter need to consider all of those condition to have appropriate total lead time.

Many researchers studied and analyzed the correlation between equipment criticality and stocking philosophy, the criticality of equipment in petrochemicals industry and distinguish the equipment into vital, essential and auxiliary equipment, and the level of criticality of equipment are Critical and Non-Critical demand [13]. Critical demand comes from the vital equipment and non-critical demand comes from essential or auxiliary equipment. There is a possibility spare parts are installed in different categorized of equipment with different criticality [13], [14].

Main contribution on defined the criticality of equipment is the production impact and stock out penalty. To handle spare parts installed in multiple equipment, stocking philosophy for each criticality is defined by service level as agreed on the stocking policy. Service level defined as percentage of demand which is satisfied directly from stock on hand, also to determine service level is correlation between random time point and inventory position and the stock out occurred based on total demand from critical and non-critical demand. [13]. If any same material demand from both criticality then the available material will be served for critical demand first and became backorder for non-critical demand.

2.4. Inventory Level

The aim of inventory is to ensure the spare parts are adequate to requirement and the order is in place with optimum value and the nature of industry and the challenge of the lead time, it is required to have a system to ensure operation is not interrupted by stock out. One of the system use to monitor and ensure stock replenishment process is satisfactory to requirement is Minimum or Reorder point level and Maximum stock level. And to satisfy uncertainty of stock out, inventory set the safety stock level.

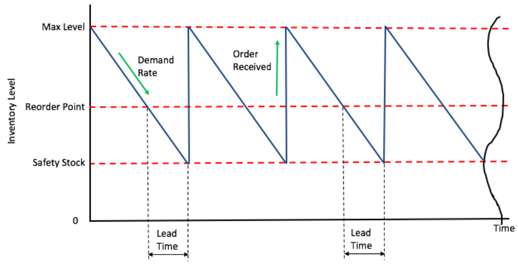

Figure 3. Inventory Cycle

It is shown in Figure 3 the cycle of inventory or stock process, where stock in inventory is reduce in parallel with time. The order process to set the stock in maximum level, procurement process starts when the stock availability is reach the re-order point. To avoid any stock out situation when the stock is reach the safety stock level, goods received processed to put the new materials in stock.

In general terms of maximum level is the maximum quantity could be held in warehouse as stock inventory or could be stated as upper level of the inventory. Maximum level calculation is related to Economic Order Quantity (EOQ) where the main variable on calculating EOQ are historical or projected demand, ordering cost on each order process and holding cost to maintain materials in stock.

The calculation of maximum level is

Max Level = EOQ + ROP + SS ………………….(1)

Where:
EOQ : Economic Order Quantity
ROP : Re-Order Pont
SS : Safety Stock

To defined the level of maximum stock need to consider other aspect in in inventory management. The main aspect to be consider as constrains are working capital cost and storage space. Hold many quantities in stock is not good enough from financial point of view, because of one of the main parts on the EOQ calculation is price of material or set up cost. When the price of material is cheap compare with ordering cost, the result on EOQ calculation is to increase the quantity of order. This condition is creating other problematic condition in storage process. There is a potential material cannot be use when needed because of expiry or damage during storage process, it is creating financial loss and storage space is other problem. As part of holding cost, storage utilization become significant aspect. Material stored in shelves for long period is increase the holding cost, such as preservation cost and loss of cost of money. Based on those constrain on the storage matters, need to consider when define the level of maximum alongside with EOQ calculation.

In one point of level stock need to replenish, it is required a set up level to ensure the re-order process is triggered. The goals of re-order point (ROP) in MRO parts is to ensure stock is always available in shelve at least one part. [15]. When the stock on hand reached one item, the replacement order started to avoid any stock out situation. The main parameter on calculate ROP is lead-time and the demand, that parameter could be formulized as:

ROP = d x L …...……………………………… (2)

Where: d: Demand in time period
L: Order Lead Time

in MRO inventory control is a challenge because of the uncertainty of demand and lead time. In production goods inventory control demand could be defined based on historical sales data or sales target. Sales data as demand data to calculate risk on production management. [16]. Demand on MRO process is depending on the equipment condition and maintenance strategy for the equipment. Other challenge is a material installed in multiple equipment with different equipment and maintenance strategy. Inventory management who have responsible to ensure stock availability need to consider those uncertain condition and maintenance or equipment strategy to have optimum stock level.

2.5. Safety Stock

The challenge in MRO process is uncertainty condition, either uncertainty because of unpredictable increase on the demand or delay on delivery process. Those two kinds of uncertainty are the most cases happened in MRO's stock system. Increase of the demand usually occurred because of any anomaly in production process or any un-predictable condition on the equipment. Lead time is other challenge especially where the manufacturer of the equipment is overseas from production plant. Internal and external condition always need to consider in calculate the lead time, one of possibility of delay from external process is custom process. At least there are twice on the custom processes, first is in the original manufacture's country and the second process is custom in production plant's country.
To avoid any production disruption because of spare parts are not available, inventory management always set a level of safety stock level. Many researchers already studied the correlation between safety stock and loss of production or sales. To ensure no back order because of stock not available required to determine the safety stock level in monthly basis refer to production quantity [17]. Other author service level was studied constrain to define safety stock. [18], also considered safety stock as fairly permanent investment in inventory and because of safety stock is always available in average, it is similar with fix asset in accounting purpose. [19]. The relationship between single item safety stock and service level is straight forward when the safety stock is increase will always increase the investment cost as shown in figure 4.

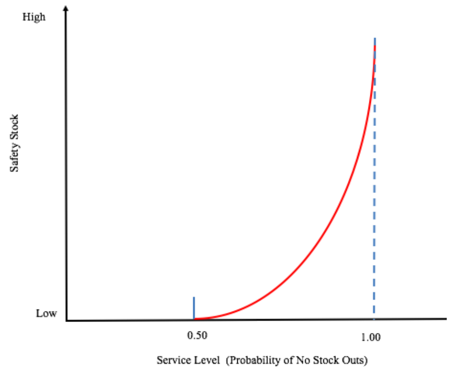

Figure 4. Safety Stock vs Service Level
(Source: Tersine, 1994, p. 204)

Figure 5 shown the deviation because of abnormal in requirement of materials. When abnormal requirement occurs, material needs before the replenishment process completed.

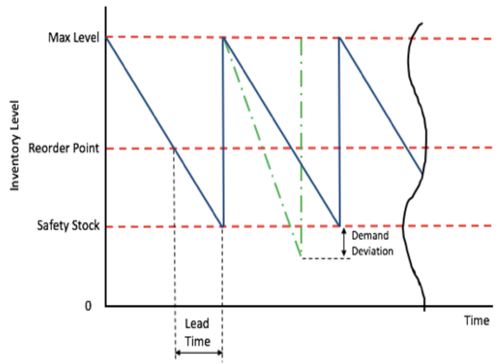

Figure 5. Inventory Cycle with Demand Deviation

And figure 6 shown the abnormal condition because of the delay on the replenishment process. To avoid any stock out or back order condition management always set up a level of safety stock. There is no fixed formula or rigid procedure to follow in determining safety stock. [19].

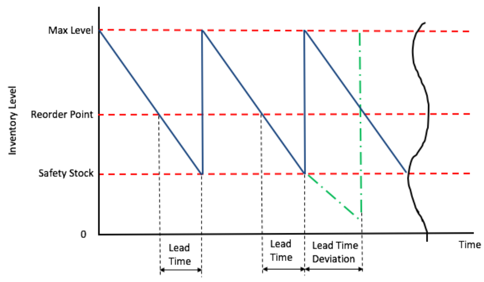

Figure 6. Inventory Cycle with Lead Time Deviation

Main contribution on calculated safety stock are based on demand, lead time, stock out costs, service level, production process and external factors. Many researchers investigate and tried to find the optimum safety stock based on internal and external consideration and some of researchers compared the proposed calculation to find which calculation provide the most cost efficient.

Shortage of supply because of uncertainty of demand have been investigate by many researchers. Thee correlation of safety stock and shortage occurrence, increase the level of safety stock is reduce the shortage occurrence [20]. The backorder or shortage model extremely overestimate compare with required safety stock, it is relatively because of uncertainty of demand during lead time and short of review period. [18]. There are internal and external process impacted to safety stock calculation, standard deviation could be added to accommodate the external factors, this proposed method demonstrated agreed service level can be achieve with significant higher inventory level. [21]. Related to uncertainty in internal production process investigated the correlation of production disruption and safety stock. [22]. Maintaining buffer stock or safety stock is efficient in terms of cost especially when the process shifts and occurrence of machine breakdown frequently take place. The production capacity stage is needed to increase the safety stock by added a correction factor to obtain a stock out probability when the production is incapacitated and over production could be used as buffer stock to anticipated future demand and the safety stock is not required when the production capacity can process stock replenishment 100% of the demand [23]. Factors of stock out are fluctuation of demand and machinery breakdown. [17]. Those condition have impact on the production process and could generate customer dissatisfaction. There are large numbers of constrain and constant in production capacity are condition created the difficulty to find the best solution of safety stock.

Many researchers already investigate and proposed the model to have optimum safety stock with high service level in production or distribution process, an investigation and comparisons of two models of safety stock, Guaranteed-Service Level (GSA) and Stochastic-Service Approach (SSA) have been done. Result of that comparison analysis is not very large the cost different between GSA and SSA, the different for those two approaches only 4% at most. The superiority of one approach of the other is on flexibility of operating cost parameter and stock point's level of flexibility. [24].

To find the most optimum safety stock level, comparison study of safety stock has been done and there is no superior approach on calculate safety stock, the model is depending on the specific condition on each process. The main area has impact on the safety stock calculation are variation on demand and variation of replenishment time. [12].

3. Method

The objective of maintenance process for routine maintenance, corrective maintenance or turnaround is to ensure the reliability of equipment is in best performance at any time. Time period of maintenance or downtime of the equipment need to ensure as short as possible, to ensure the maintenance process is on schedule is require have ready spare part. Main constrain for maintenance team is the lead time of the materials regardless the criticality of materials. Many literatures propose to have safety stock level in inventory to avoid any stock out situation and mostly they are focus on the deviation of delivery time to ensure the stock is adequate to the demand.

In the other side, inventory need to set as low as possible, this is to reduce the holding cost of inventory. This contradictive situation needs to look for the meeting point. It is required to have cost balance between stock out and holding cost. In fact, not all material is required to have safety stock because of there are alternatives process of maintenance to ensure the equipment is still on services. The alternative such as:

- Have a standby back-up unit of equipment
- By passed the process
- Use other alternate spare parts, or
- Repair process for the defective equipment can wait for certain additional time.

Based on above contradictive requirement between inventory strategy and maintenance strategy, this paper is to investigate the appropriate safety stock level with consideration of maintenance needs and inventory requirement.

There are two areas to be focuses to have maximum result on this research. First area to analyze is the risk on the maintenance activity, main focuses is on the risk analysis and investigate is the risk will occur when the spare part is not available in term of quantity and time. Other than the risk occurrence to be consider is what kind maintenance action to be performs to reduce the risk to the lowest level and the acceptable span for equipment in breakdown condition. Those information will use as basis data to calculate the appropriate criticality of spare parts compare with criticality of equipment where the spare part is installed. The challenging on this method is for common spare parts used in multi equipment. On this condition, need to decide, to be use the highest critical of the spare parts and equipment to minimize the operation disruption. To combine both criticalities, spare part and equipment, will use the risk matrix method.

In addition to the maintenance risk, from inventory perspective need to investigate and analyze the lead-time of the procurement and delivery process. In common supply process, there are two different activities on procurement process need to consider. First lead-time is internal process lead-time, different type of spare parts and different supplier having different challenges. Approach and strategy for procurement team to get an agreement with supplier is depending on several conditions. Second lead-time is external lead-time, the distance and shipment method from manufacturer to production plant have direct impact on the lead-time. Different suppliers from same or similar spare parts have different duration on the shipped the order. Those conditions create the deviation on the delivery time of the spare parts on each ordering process.

Because of uncertain condition come from internal and external organization impacted to the procurement processing time and no consistency on the delivery of spare part, need to analyze the deviation on the delivery for different criticality of spare parts. Those concerns could analyze with standard deviation calculation.

3.1. Risk Matrix

The definition of risk matrix is an assessment methodology to identify and evaluate the probability and severity of a specific expected on anticipated action or inaction to occurred. Risk assessment matrix is a combination of probability and severity and come up with different level of risk result. The two combinations of risk in this paper is combination between criticality of equipment and criticality of spare parts. The level of criticality for spare parts and equipment can describe as:

Criticality of Equipment:

- ✓ High Critical, equipment has significant contribution to production process. There is no backup equipment to support, or no other option for maintenance to repair or bypass the process if the equipment is down. If the equipment is down, there is a direct impact to the production process. Production process must to stop if the equipment not in services. Mostly, typical of those equipment are main equipment to do the production process, high value, no backup equipment, or related to safety devices to production process, and required to back to operation as soon as possible.
- ✓ Medium Critical, equipment under this criticality is has significant contribution to the production or safety in production process. There is backup equipment to support or backup process can be performed if the equipment is not in services.
- ✓ Low Critical, under this criticality category the equipment is has indirect contribution in production process. There are few options can be perform by maintenance if the equipment is not in services or accepted downtime period for this kind of equipment is longer, maintenance is not in rush time to repair the equipment
- ✓ Non-Critical, equipment under this category usually does not have direct or indirect impact to the production process or safety.

Criticality of Material:

- ✓ High Critical, material or spare part with high critical are mostly installed in high critical or safety equipment and has direct impact to the running process of equipment. Spare part is required to ready to be use at any time when it is required.
- ✓ Medium Critical, material or spare part under medium category generally is high critical spare part but have alternate if the spare part is not available or this kind of spare parts could be obtained in short period of lead-time.
- ✓ Low Critical, this kind of spare part is link to production process but many alternatives could implement if spare part is not available when required. The alternatives action is from maintenance side or from inventory side.
- ✓ Non-Critical, materials or spare part categorized as non-critical mostly all those spare parts are not serve to critical equipment, easy to get when required and common materials or spare parts

All above types of criticality equipment and spare parts are required to combine to have final criticality. To calculate the combination is using risk assessment matrix as a basis calculation.

Table 1. Criticality Risk Matrix

EQUIPMENT CRITICALITY					
	D	LC	LC	NC	NC
	C	MC	MC	LC	NC
	B	HC	MC	MC	LC
	A	HC	HC	MC	LC
		A	B	C	D
		MATERIAL CRITICALITY			

Legend:

HC : High Critical	A : High Critical
MC : Medium Critical	B : Medium Critical
LC : Low Critical	C : Low Critical
NC : Non-Critical	D : Non Critical

The combination between criticality of equipment and criticality of material as shown in Table 1 defined new criticality based on criticality of equipment and criticality of material. Equipment and material have individual criticality identified as

"A", "B", "C" and "D" critical, when both criticality combined its produce new criticalities. After both type of criticality combined, new criticality could be increase or decrees based on the risk matrix. New criticality is used for next calculation of safety stock level on this paper.

3.2. Downtime Period and Order Lead Time

Equipment is not always in-service condition, in some period need to have a break from services. The break time or called as downtime period could be planned or unplanned break down. Planned downtime such as turnaround maintenance process or because of regular maintenance, those types of maintenance are having a plan before the execution, the planning include manpower, required spare parts and duration of the downtime. Unplanned downtime is a challenge for maintenance to bring the equipment back to service as soon as possible. During the downtime period maintenance will organize the required task to avoid disruption to other equipment and overall processes and reduce the downtime as short as possible. In general, the downtime period could be defined as:

- Urgent is the downtime period of the equipment is not acceptable. The equipment need to back on normal condition as soon as possible. Urgent type usually applicable for high critical equipment and maintenance have no alternative option to extend the downtime period.
- Immediate is the downtime period of the equipment have tolerance in certain time. This type usually applicable for critical equipment however maintenance have other option to extend the downtime by reduce the production capacity.
- Moderate is the downtime period of equipment have longer time is acceptable. On the moderate downtime usually applicable for less critical or redundant equipment and maintenance have few options to ensure the production capacity is not disrupted.

Availability of required materials is other challenge to perform maintenance task. Ordering process from material reserved till received by requestor is a challenge for supply process to satisfy the requirement. Supply section need to consider acceptable downtime period with total lead time. Comparison of the downtime period and total lead time is considered on this paper, both timing period consider as acceptable service level.

4. Result and Discussion

Generally, the models of safety stock are distinguished based on the characteristic of industry. In manufacturing or distribution industry, main factor of the models is based on forecasting and lead time, where the forecast model is referring to historical data or sales target. In MRO process, normally safety stock model is based on criticality of equipment and lead time. Both models are had similarity to measure the achievement. Target to be achieved is set based on agreement in inventory procedure, the target is to minimize the back order or stock out situation indicated as percentage of service level.

The challenge of inventory for MRO spares are dependency on the equipment condition and there are spares with low consumption per year. Those conditions are always had discussion between engineering or maintenance team with inventory control team, because of different objective and priority. Engineering or maintenance achievement target is to ensure equipment and plant reliability operate with high performance and with low downtime, in other side inventory control need to ensure stock stored in warehouse under inventory account is utilize with high turnover.

The purpose of model in this paper is to response the gap between engineering and maintenance with inventory control. Proposed model is to have more reliable target of service level based on the combination of criticality of equipment and spares throughout the risk matrix. Furthermore, the model incorporated with comparison of replenishment time and downtime of the equipment. Comparison of replenishment time and acceptable downtime period is a parameter for inventory control to satisfy the customers. As a basis to calculate requirement of spares is use MTBF of the spares and equipment, the figure of MTBF is referred to manufacturer data or based on data from condition monitoring program. The proposed model be expected to meet user satisfaction with optimum inventory value.

It is indicated the different result between three safety stock calculation model standard calculation model with constant demand and variable lead time, MTBF with poison process and MTBF with lead time and downtime comparison. Also, there is a contribution to SSL from lead time and downtime period.

Main contributor to set SSL in MTBF-Poisson process model only service level, there is no involvement of lead time and downtime and in certain level result of the calculation is higher than total spares installed in equipment. And MTBF-Poisson process result is provided single level of SSL for different downtime period because of the acceptable downtime is not part of the model. The MTBF-Poison process model purely calculated based on maintenance or operation standpoint only. With MTBF-Poisson model inventory need to spend more for inventory holding cost.

With standard SSL with constant demand and variable lead time model, service level and deviation of lead time are main contributor on the calculation. This model provides constant result on each service level and because of standard SSL with constant demand and variable lead time model is calculated based on inventory control standpoint, in case of high critical spares is not meet with maintenance requirement. Where the level of SSL is less than installed spares in equipment.

Refer to the combination of criticality, criticality of spares with less critical but installed in high critical equipment will increase the level of criticality also increase on the service level target. And spares with high critical but installed in less critical equipment will reduce the criticality and also reduce the target of service level. Same spares are possible installed in different critical equipment, on this case the calculation is used the highest equipment criticality to ensure there is no stock out situation for that spares. In term of replenishment time, the calculation also considers accepted downtime period, where this condition could increase the confidence level of inventory control to process the delivery of the spares with lower cost as long as the delivery time is still within the downtime range.

The propose of the constrain of maximum level is to ensure no overstock in inventory. Figure 8, 9 and 10 show the correlation and comparison between those three models. With MTBF-Poison process and standard SSL calculation models, SSL is increase linear with the service level and the level of safety stock is constant refer to the service level. Proposed model shown level of safety stock is depend on the downtime period and service level. SSL is increase for the higher service level in accordance with the downtime period, more critical a spare need to have safety stock for longer period to ensure the stock availability.

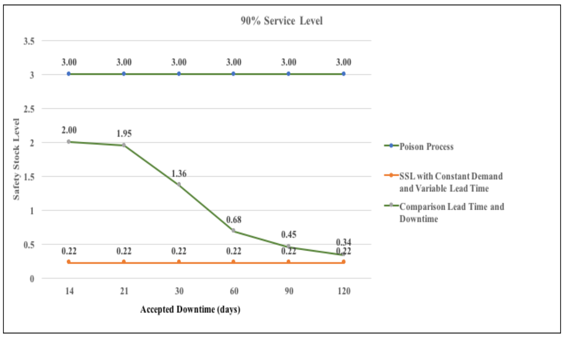

Figure 8. Comparison with 90% Service Level

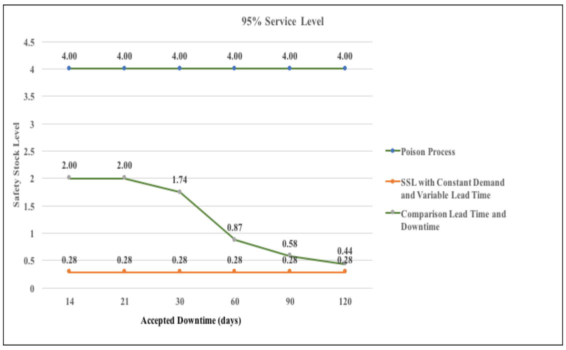

Figure 9. Comparison with 95% Service Level

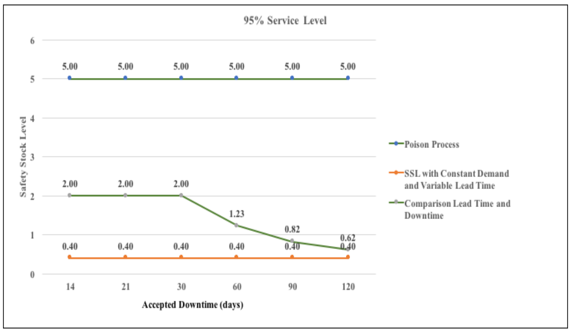

Figure 10. Comparison with 99% Service Level

With above result of the proposed model, can be concluded the proposed model is have constructive result and aligned with the early hypothesis and as expected. Where information of downtime period is support inventory control to optimize the safety stock level and impacted to inventory cost to be spend.

5. Conclusion

This paper has been studied the safety stock calculation and compared with earlier researcher. Based on this study, the safety stock level calculation, lead time is one of major contributor on the calculation and this is aligned with previous researchers. Where the safety stock level is set to cover a deviation on the lead time and/or deviation on required quantity.

Other parameter used to calculate safety stock level is a target of service level or customer satisfaction, where the service level is set to avoid any stock out situation or back order. With combination of criticality material and equipment is increase the assurance of inventory control to set a service level and incorporated in the safety stock calculation. With combination of criticality approach the stock out target or service level is not only look into single point of view, this approach also provides satisfactory for both parties, maintenance as receiver of services and inventory control as provider of services.

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