Application of Economic Order Quantity (EOQ) for Make-To-Order (MTO) Business

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Abstract

Research about the implementation of the Economic Order Quantity (EOQ) model is mostly done only for implementation in Make-To-Stock (MTS) companies. There has not been much recent research about the implementation of the EOQ model to companies that use make-to-order (MTO) business production strategy. Therefore, by considering the research gap as well as the need of MTO businesses to reduce their costs, the implementation of the EOQ model is applied to PT X, which is an MTO company that produces steel wheel disc. The aim of this research is to discover a better order quantity planning method by comparing the holding cost between PT X's production system before and after the implementation of the EOQ model. The results of analysis, calculation, and validation of order quantity planning using the EOQ model showed that the implementation of the EOQ model for order quantity planning in PT X can reduce the number of losses caused by holding costs. The research is conducted assuming the supplier is a make-to-stock producer that is capable of meeting production demand with at most 1 week lead time.

Keywords
Economic Order Quantity (EOQ), Make-To-Order (MTO), Order Quantity Planning, Holding cost

1. Introduction
All businesses have to control their inventory efficiently to operate at an acceptable level. The objectives of inventory management are to provide the required level of customer service and to reduce the sum of all costs involved (Arnold et al. 2008). They need to prevent stockout and overstock of their supplies to optimize costs incurred by their inventory. To achieve these objectives, inventory managers must know how much materials should be ordered at one time and when should an order be placed (Bushuev et al. 2015). Several approaches to effective inventory control have been researched and implemented especially in the make-to-stock business sector. One of the classic approaches to effective inventory control is the optimization of order quantity planning using the Economic Order Quantity (EOQ) model. Its implementation has been researched since 1913 and the model has been continuously improved to be one of the most robust models in order quantity planning. However, research about the implementation of the EOQ model is usually done only to make-to-stock (MTS) companies. One of the most recent research about implementation of the EOQ model to an MTS company is done by Gozali et al. (2020). Another notable research about implementation of the EOQ model in an MTS company is done by Jiraruttrakul et al. (2017). The result of the implementation of the EOQ model in those research is a reduction in total annual inventory cost of a real MTS company.

There has not been much recent research about the implementation of the EOQ model to companies that use make-to-order (MTO) business production strategy. The research is also mostly done with different objectives. Based on a review of inventory lot sizing papers (Bushuev et al. 2015), there have not been many attempts on using the EOQ model to calculate the order quantity of MTO businesses' raw materials. The survey of lot sizing and scheduling practices in Brazilian companies (Tomotani and Mesquita 2017) showed that most MTO businesses prefer the 'lot-for lot' order quantity decision rule. Despite this, there are a few notable researches about implementation of EOQ model in MTO businesses. One of the notable researches is made by Chun-hua and Xue-feng (2010). The researchers adjusted the classic EOQ model (Harris 1913) and developed a new, theoretical EOQ model specifically for a single product, multi-supplier MTO supply chain. Overall, progress of research about implementation of the EOQ model in MTO businesses has been focused only on the development of theoretical models. By comparing the research progress between the implementation of EOQ model to MTS businesses and the implementation of EOQ model to MTO businesses, it is concluded that there has not been any significant research about the implementation of EOQ model to MTO businesses. Therefore, by considering the research gap as well as the need of MTO businesses to reduce their costs, this research aims to close the gap by researching the implementation of the classic EOQ model (Harris 1913) to a real MTO company.

To research the implementation of EOQ in make-to-order companies, the business production strategy of PT X is analyzed. PT X is a company in East Java Province, Indonesia, that operates in the automotive sector, specifically on the manufacture of truck components. The component produced by PT X is a steel wheel disc which is part of the tire attachment on a truck. In its production system, PT X uses a make to order system because they use customer demand as the basis for planning their production process. To start the production process, PT X requires raw materials such as iron plates and bars. These raw materials are usually ordered from suppliers of PT X in China and Korea. The lead time for the orders is three months. Before placing an order for its raw materials, PT X must plan the quantity that it will order. Currently, plans for each of PT X's raw materials order quantity is made based on the forecast of future demand. These forecasts are based on PT X's historical data.

The raw materials order quantity planning method currently used by PT X has been delivering order quantities that are either greater or lesser than the number of raw materials required for production (based on actual demand for finished products). This resulted in the emergence of an on-hand inventory of raw materials. Too much on-hand inventory of raw materials can cause losses to a company because of the holding cost. This cost can be reduced by applying another order quantity calculation method.

1.1 Objective

The objective of this research is to research the possibility of reducing PT X's holding cost by implementing the Economic Order Quantity (EOQ) model for PT X's raw materials order quantity planning process. Considering the low amount of research about EOQ model implementation in make to order businesses, the possibility of the method failing or succeeding in decreasing the holding cost have never been confirmed. The method may still fail to reduce the number of losses caused by holding costs, concluding that the method currently used by PT X is relatively better. Through this research, researchers hope to discover a better order quantity planning method by comparing the holding cost between PT X's production system before and after the implementation of the EOQ model.

2. Literature Review

Economic Order Quantity

Based on a state-of-the-art review of supply planning and inventory control under uncertainties in MRP environments (Dolgui and Prodhon 2007), it is known that the Economic Order Quantity (EOQ) model is the easiest technique to use for order quantity planning. EOQ is also one of the most robust models as it is still reliable despite large errors in forecasting. These traits enable EOQ to be the standard lot-sizing rule in various production planning software. However, there are several assumptions that need to be fulfilled before implementing the EOQ model (Arnold et al. 2008). The assumptions on which the EOQ model is based upon are as follows:

Demand is relatively constant and is known.

- The item is produced or purchased in lots or batches and not continuously.
- Order preparation costs and inventory-carrying costs are constant and known.
- Replacement occurs all at once.

The fulfillment of these assumptions can be depicted through the following graph.

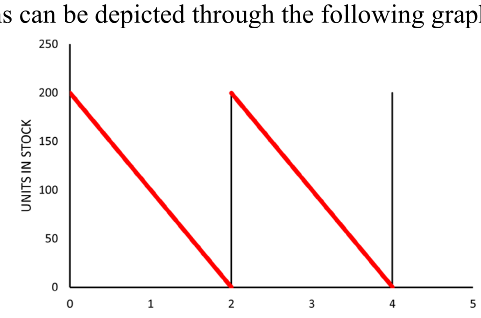

Figure 1. Production period (Weeks) versus Units in Stock (inventory).

The red line in the preceding graph depicts the ideal decrease rate which is a uniform decrease rate. Products that have an inventory graph showing a uniform decrease rate similar to Figure are interpreted as products that can fulfill the assumptions of the EOQ model (Arnold et al. 2008).

After the preceding assumptions have been met, the EOQ of an item or product group can be calculated. Based on several literatures (Erlenkotter 1990 and Stuart 2004), calculation of the EOQ is done through the following formula:

$$EOQ = \sqrt{\frac{2\lambda k}{h}} = \sqrt{\frac{2\lambda k}{\alpha c}}$$

When calculating EOQ, it is important to only include costs that are relevant to each of the equation's variables. A practical description of each variable is as below (Stuart 2004; Arnold et al. 2008; and Ali 2020):
λ = a constant demand per unit of time; the unit of time must match other variables' unit of time.
c = a constant, per-unit purchase cost; purchase cost can also be expressed as price per unit.
k = ordering cost = a fixed cost per order; only include fixed costs that increment based on the number of orders.
h = a constant, per-unit holding cost; a portion of the money & its time value spent to hold each purchased item.
α = i = carrying cost rate = the cost of money, typically an interest rate; may represent the time value of money or other aspects that affect the holding cost of the purchased item (e.g. opportunity cost of other investment).
q = the decision variable = the order size.

Make-To-Order
Make-To-Order (MTO) is a business production strategy in which production of an item begins only after a confirmed customer order is received. Because the strategy waits for customers to make orders of production, it resembles the action of customers pulling products out of the factory (pull-type supply chain operation). This strategy typically allows consumers to purchase products that are customized to their specifications (Reid and Sanders 2013). The following is a flowchart describing the MTO production strategy of PT X:

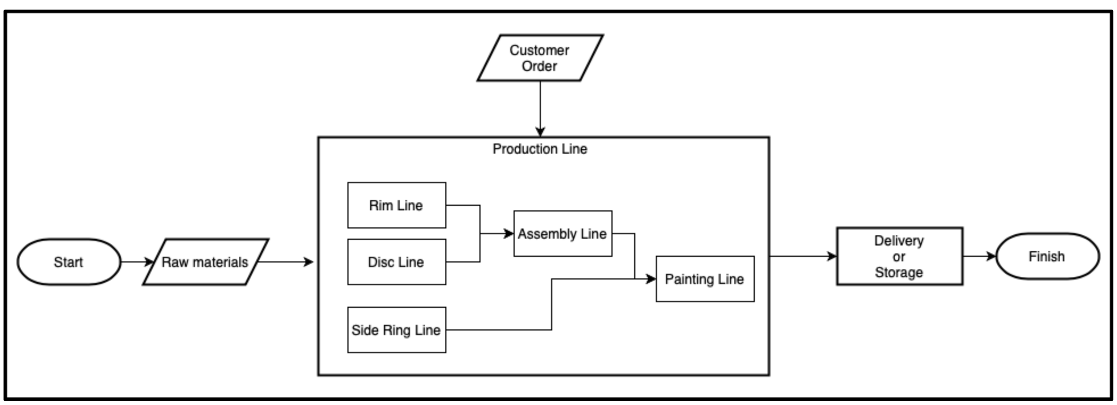

Figure 2. Flowchart describing the MTO production strategy of PT X.

The production strategy flowchart from PT X starts with a forecast of demand for finished products which is broken down into a raw material forecast made by the PPIC department of PT X. Based on the raw material forecast, the PPIC department provides its data to the purchasing department to make raw material purchases. To purchase raw materials, it needs a lead time of three months. This lead time is also one of the reasons why PT X needs to do forecasting in advance. At this time, the customer orders are issued by PT X's customers. With this customer order, the PPIC department can improve the actual raw material requirements and plan the production of the steel wheel disc. After the production plan has been made, the production department can start the production process as stated in the flowchart of the production line section. Finally, the products will be sent directly to the customer or temporarily stored in the warehouse.

Implementation of Economic Order Quantity in the inventory system of Make-To-Order businesses
There has not been much recent research about the implementation of the EOQ model to companies that use make-to-order (MTO) business production strategy. Based on a review of inventory lot sizing papers (Bushuev, M. A. et al. 2015), there have not been many attempts on using the EOQ model to calculate the order quantity of MTO businesses'

raw materials. The survey of lot sizing and scheduling practices in Brazilian companies (Tomotani and Mesquita 2017) showed that most MTO businesses prefer the 'lot-for lot' order quantity decision rule. This is because their customer specifies the production quantity, therefore directly affecting the number of raw materials ordered (Arnold et al. 2008). However, some standardized raw materials exist.

One of the notable researches is made by Chun-hua and Xue-feng (2010). The researchers adjusted the classic EOQ model (Harris 1913) and developed a new, theoretical EOQ model specifically for a single product, multi-supplier MTO supply chain. The researchers concluded that the main constraint in its research is the industry replenishment speed. Another notable and more recent research about the implementation of the EOQ model to MTO businesses is made by Qiao et al. (2017) and Qiao et al. (2019). Both researches adjusted the classic EOQ model for solving the lot-sizing problem in MTO companies with the objective of maximizing profits under carbon emission caps. The research done by Qiao et al. (2019) also provided some managerial suggestions for companies on how to balance carbon management and profit earning. It concluded that although improving product sustainability requires extra cost, it can attract more green consumers, which can bring in more revenue. Despite the recent developments however, research that focused solely on reduction of inventory cost through reducing holding cost has never been done to a MTO company.

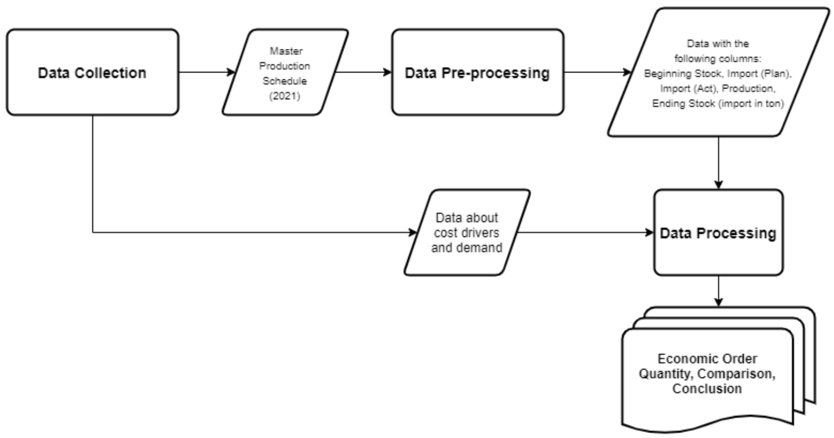

Figure 3. Research methodology flow chart.

3. Methods

This research is segmented into several phases that are illustrated by the flow chart above. The first phase is data collection, followed by data pre-processing and data processing. Data collection process in this study was conducted by collecting the report or documentation of the monthly production plan made by PPIC Department of PT X as well as inquiring data about its cost drivers and data about PT X's yearly demand. In the monthly production plan, there are several sections such as stock rules, Master Production Schedule (MPS) and Material Requirement Planning (MRP), as well as charts that reflect the ending stock of each raw material. After that, the data will be pre-processed. In this study, data preprocessing was carried out by extracting and filtering the data needed for calculations. The extracted data is taken from the MRP section which includes some information such as beginning stock, planning and actual imports, production or usage (raw material to be used), ending stock, and the amount of imports in tons each week. By processing the collected and preprocessed data through the EOQ model, researchers calculate the Steel Plate 9 mm order quantity. The processed data (results of the EOQ model) is then compared with the currently used order quantity planning method to determine the best performing method.

The comparison process between the before and after the implementation of the EOQ model is carried out in two stages. The first stage is the comparison of the ending stock chart and the second stage is the comparison of the total cost. Area under the ending stock curve can be interpreted as the use of storage space by the ending stock. The use of this storage space incurs holding cost, hence it can also be interpreted that the larger the area under the curve then the greater the holding cost that is incurred. By comparing the holding cost, which method is more profitable can be determined. Meanwhile, the total cost comparison is done by calculating and comparing the total cost incurred before and after the implementation of the EOQ model. By comparing the total cost, which method is more profitable can also be determined. After the comparison process, a validation process is conducted to test the significance of the results of the previous comparison stages. The process is carried out through statistical tests that have been selected according to the nature of the data. Lastly, conclusions are then inferred from the results.

4. Data Collection

Production data for the research is collected from the Materials Requirement Planning (2021) of PT X. The production data about raw material inventory is measured per sheet of raw material. Raw materials used by PT X are imported from a supplier who has 3 months lead time in the production and delivery process. In addition, there is a constraint where this supplier can only ship once a month. Therefore, it can be seen in table 1, the import (act) column which shows the actual import amount of PT X is only carried out once a month.

Table 1. Steel Plate 9 mm Order Plan Data before the implementation of EOQ model

Month	Week	Beginning Stock	Import (Plan)	Import (Act)	Production	Ending Stock	(import in ton)
January	1	860,4	0,0	0,0	216,0	644,4	0,0
	2	644,4	0,0	0,0	216,0	428,4	0,0
	3	428,4	0,0	0,0	216,0	212,4	0,0
	4	1012,4	0,0	0,0	216,0	796,4	0,0
February	5	796,4	0,0	0,0	261,0	535,4	0,0
	6	535,4	0,0	0,0	261,0	274,4	0,0
	7	274,4	0,0	0,0	261,0	13,4	0,0
	8	1013,4	0,0	0,0	261,0	752,4	0,0
March	9	752,4	0,0	0,0	267,0	485,4	0,0
	10	485,4	0,0	0,0	267,0	218,4	0,0
	11	218,4	0,0	0,0	267,0	-48,6	0,0
	12	895,4	0,0	0,0	267,0	628,4	0,0
April	13	628,4	0,0	0,0	240,0	388,4	0,0
	14	388,4	0,0	0,0	240,0	148,4	0,0
	15	148,4	872,0	872,0	240,0	780,4	160,4
	16	780,4	0,0	0,0	240,0	540,4	0,0
May	17	540,4	0,0	0,0	156,0	384,4	0,0
	18	384,4	0,0	0,0	156,0	228,4	0,0
	19	228,4	0,0	0,0	156,0	72,4	0,0
	20	72,4	654,0	654,0	156,0	570,4	120,3
June	21	570,4	0,0	0,0	264,0	306,4	0,0
	22	306,4	0,0	0,0	264,0	42,4	0,0
	23	42,4	0,0	0,0	264,0	-221,6	0,0
	24	-21,6	1199,0	1199,0	264,0	913,4	220,6
July	25	913,4	0,0	0,0	300,0	613,4	0,0
	26	613,4	0,0	0,0	300,0	313,4	0,0
	27	313,4	0,0	0,0	300,0	13,4	0,0
	28	13,4	1308,0	1308,0	300,0	1021,4	240,7
August	29	1021,4	0,0	0,0	276,0	745,4	0,0
	30	745,4	0,0	0,0	276,0	469,4	0,0
	31	469,4	0,0	0,0	276,0	193,4	0,0
	32	193,4	1199,0	1199,0	276,0	1116,4	220,6
September	33	1116,4	0,0	0,0	324,0	792,4	0,0
	34	792,4	0,0	0,0	324,0	468,4	0,0
	35	468,4	0,0	0,0	324,0	144,4	0,0
	36	144,4	1199,0	1199,0	324,0	1019,4	220,6
October	37	1019,4	0,0	0,0	321,0	698,4	0,0
	38	698,4	0,0	0,0	321,0	377,4	0,0
	39	377,4	0,0	0,0	321,0	56,4	0,0
	40	56,4	1199,0	1199,0	321,0	934,4	220,6
November	41	934,4	0,0	0,0	330,0	604,4	0,0
	42	604,4	0,0	0,0	330,0	274,4	0,0
	43	274,4	0,0	0,0	330,0	-55,6	0,0
	44	-55,6	1199,0	1199,0	330,0	813,4	220,6
December	45	813,4	0,0	0,0	174,0	639,4	0,0
	46	639,4	0,0	0,0	174,0	465,4	0,0
	47	465,4	0,0	0,0	174,0	291,4	0,0
	48	291,4	654,0	654,0	174,0	771,4	120,3

Table 1 is a MRP table of the raw material type steel plate 9 mm. Steel Plate 9 mm has been chosen as the raw material which order quantity will be planned using the EOQ model. Each sheet of the raw material weighs approximately 184,13 kg. Steel Plate 9 mm is chosen to fulfill the EOQ model assumptions. This is proven by the approximately uniform decrease rate of Steel Plate 9 mm's Ending Stock inventory as seen on the chart below (Arnold et al. 2008).

The results of the data from the ending stock are then represented using graphs. The results of the ending stock chart can be seen below.

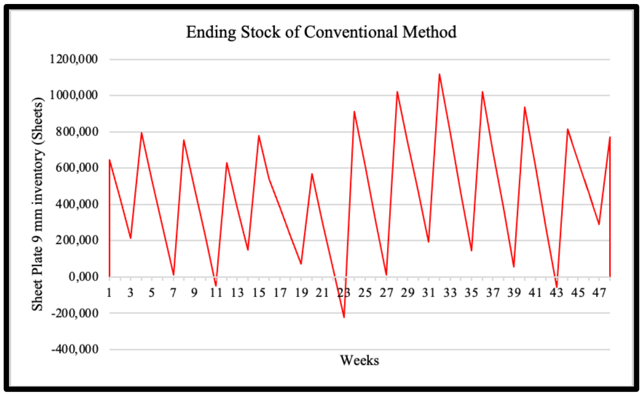

Figure 4. Ending Stock Chart of Steel Plate 9 mm before the implementation of the EOQ model

From the chart, it can be seen that the ending stock for Steel Plate 9 mm is decreasing at an approximately uniform rate. This is concluded because the decrease rate for Steel Plate 9 mm's ending stock is similar to the uniform decrease rate depicted in Figure 1. Therefore, Steel Plate 9 mm is concluded to be better at fulfilling the assumption required for the EOQ model compared to the other raw materials. From the chart it also can be seen that the highest value on the ending stock can reach 1116.4, which means that there are quite a lot of raw materials that need to be accommodated in the warehouse. On weeks 11, 23, and 43, it can be seen that the company is out of stock so that it cannot meet real demand.

Data about cost drivers for the research is collected from the testimony of PT X managers as well as the researchers' observation of PT X business operations. Cost drivers that will be the input for the EOQ model are:

- c = a constant, per-unit purchase cost = 1000 $/Ton
- k = ordering cost = around $293.32 - $324.19; take average of the range = $308,755 / Order by import fees (World Freight Rates 2020)
- h = a constant, per-unit holding cost = α*c = 10% * $1000 = $100
- α = i = carrying cost rate = 10% annually

5. Results and Discussion

5.1 Numerical Results

The data that has been collected in the Data Collection chapter can then be processed directly by using the EOQ Model calculation. The formula and calculation results of the EOQ Model can be seen in the calculations below.

$$EOQ = \sqrt{\frac{2\lambda k}{h}} = \sqrt{\frac{2*2540,35*308,755}{100,00}} = 125,2475159 \approx 126\, Ton$$

The results of the EOQ model calculation are in tonnes, while the plan order at PT X is calculated in sheet units. Therefore, the results from the calculation of the EOQ model still need to be converted into sheet units. 1 sheet of raw materials weighs 0.2029685 tons so the results from the EOQ model calculation need to be divided by 0.2029685. These calculations can be seen below.

$$EOQ = 126 \text{ Ton} : (0,2029685 \frac{ton}{sheet}) = 617,0785189 \approx 618 \text{ sheets of Steel Plate 9 mm each order}$$

From the results of the EOQ calculations that have been obtained, then the number of order frequencies can be calculated within a year. The result of this calculation does not necessarily have the exact same number as the result of the plan order data in table 2, but the value will not be much different from the calculation result. The formula and calculation for the number of ordering frequencies can be seen below.

$$N = \frac{\lambda}{EOQ} = 20,28 \approx 21 = \text{number of orders per year}$$

Results of the calculation will then be used for order quantity planning for Steel Plate 9 mm. Orders of the raw material by the size of EOQ are scheduled to arrive whenever the demand forecast (forecast of the production process that uses the raw material) is larger than the beginning stock of the planning period. Below is the result of weekly order quantity planning using the EOQ model.

Month	Week	Beginning Stock	Import (Plan)	Import (Act)	Production	Ending Stock	(import in ton)
January	1	860,4	0,0	0,0	216,0	644,4	0,0
	2	644,4	0,0	0,0	216,0	428,4	0,0
	3	428,4	0,0	0,0	216,0	212,4	0,0
	4	212,4	618,0	618,0	216,0	614,4	126,0
February	5	614,4	0,0	0,0	261,0	353,4	0,0
	6	353,4	0,0	0,0	261,0	92,4	0,0
	7	92,4	618,0	618,0	261,0	449,4	126,0
	8	449,4	0,0	0,0	261,0	188,4	0,0
March	9	188,4	618,0	618,0	267,0	539,4	126,0
	10	539,4	0,0	0,0	267,0	272,4	0,0
	11	272,4	0,0	0,0	267,0	5,4	0,0
	12	5,4	618,0	618,0	267,0	356,4	126,0
April	13	356,4	0,0	0,0	240,0	116,4	0,0
	14	116,4	618,0	618,0	240,0	494,4	126,0
	15	494,4	0,0	0,0	240,0	254,4	0,0
	16	254,4	0,0	0,0	240,0	14,4	0,0
May	17	14,4	618,0	618,0	156,0	476,4	126,0
	18	476,4	0,0	0,0	156,0	320,4	0,0
	19	320,4	0,0	0,0	156,0	164,4	0,0
	20	164,4	0,0	0,0	156,0	8,4	0,0
June	21	8,4	618,0	618,0	264,0	362,4	126,0
	22	362,4	0,0	0,0	264,0	98,4	0,0
	23	98,4	618,0	618,0	264,0	452,4	126,0
	24	452,4	0,0	0,0	264,0	188,4	0,0
July	25	188,4	618,0	618,0	300,0	506,4	126,0
	26	506,4	0,0	0,0	300,0	206,4	0,0
	27	206,4	618,0	618,0	300,0	524,4	126,0
	28	524,4	0,0	0,0	300,0	224,4	0,0
August	29	224,4	618,0	618,0	276,0	566,4	126,0
	30	566,4	0,0	0,0	276,0	290,4	0,0
	31	290,4	0,0	0,0	276,0	14,4	0,0
	32	14,4	618,0	618,0	276,0	356,4	126,0
September	33	356,4	0,0	0,0	324,0	32,4	0,0
	34	32,4	618,0	618,0	324,0	326,4	126,0
	35	326,4	0,0	0,0	324,0	2,4	0,0
	36	2,4	618,0	618,0	324,0	296,4	126,0
October	37	296,4	618,0	618,0	321,0	593,4	126,0
	38	593,4	0,0	0,0	321,0	272,4	0,0
	39	272,4	618,0	618,0	321,0	569,4	126,0
	40	569,4	0,0	0,0	321,0	248,4	0,0
November	41	248,4	618,0	618,0	330,0	536,4	126,0
	42	536,4	0,0	0,0	330,0	206,4	0,0
	43	206,4	618,0	618,0	330,0	494,4	126,0
	44	494,4	0,0	0,0	330,0	164,4	0,0
December	45	164,4	618,0	618,0	174,0	608,4	126,0
	46	608,4	0,0	0,0	174,0	434,4	0,0
	47	434,4	0,0	0,0	174,0	260,4	0,0
	48	260,4	0,0	0,0	174,0	86,4	0,0

However, the result of order quantity planning above can only be implemented for PT X if PT X has a make-to-stock supplier that can ship the raw materials needed without a constraint of only 1 shipment per month. This constraint also obstructs the EOQ to be optimized further.

Total Cost Comparison

After comparing the graph between before and after implementing the EOQ model, the next step is to compare the total cost (total inventory cost) between before and after implementing the EOQ model. The formula used in this calculate total inventory cost can be seen as follows (Harborne 2004):

- Purchase Cost = $c\lambda$
- Ordering Cost = $\frac{\lambda}{q}k$
- Holding Cost = $\frac{q}{2}h$
- The price of steel wheel disc = $46,7

	Before implementing EOQ Model		After implementing EOQ Model	
Ordering cost	$	(3.667,55)	$	(6.224,97)
Holding Cost	$	(10.693,06)	$	(6.300,00)
Purchase Cost	$	(2.540.350,00)	$	(2.540.350,00)
Profit	$	8.158.500,00	$	8.761.200,00
Total	$	5.603.789,40	$	6.208.325,03

From the total cost table, it can be seen that the ordering cost after implementing the EOQ model is higher because after implementing EOQ, companies will make more orders. This is done to minimize the amount of on-hand inventory that is too much. It can be seen in the holding cost, that the nominal holding cost after implementing the EOQ model is smaller, this supports the statement in the previous sentence where the higher order frequency with the more economical nominal orders can reduce the amount of on-hand inventory. Purchase costs are the same before and after implementing the EOQ Model because the demand and purchase costs are considered the same. On the profit side, the total profit after the implementation of the EOQ Model is greater because raw materials can always meet the real demand, unlike before the implementation of the EOQ Model where there is a stockout so that it cannot meet real demand. A better total cost was obtained after implementing the EOQ Model where the profit was $ 604,535.64 higher.

5.2 Graphical Results

From the plan order data after using the EOQ model, the results of the new ending stock are obtained. The results of the data from the ending stock are then represented using graphs. The results of the ending stock chart after using the EOQ Model can be seen below.

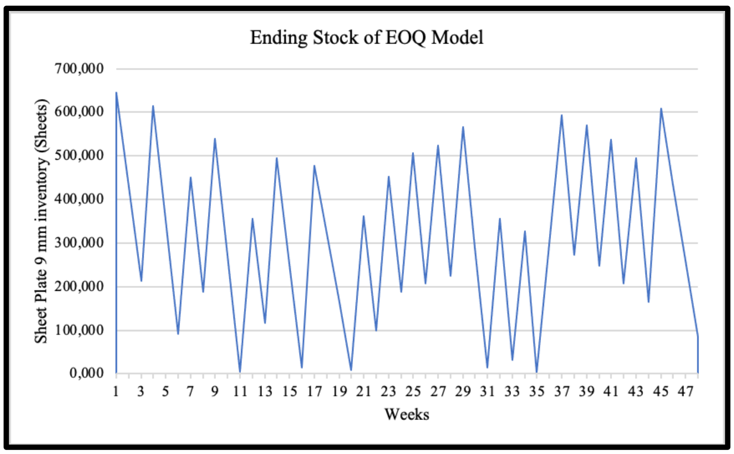

Figure 5. Ending Stock Chart of EOQ Model

From the chart, it can be seen that orders that are represented by each peak happen more frequently. This is done through the fitted EOQ model to prevent raw material stockout. The highest value on this graph is 644.4, which means that there are quite a lot of raw materials that need to be accommodated in the warehouse, but this figure is still much better than before the implementation of the EOQ Model in the plan order data.

Chart Comparison

After calculating data using the EOQ model, researchers begin to compare the calculation results and graphs between the ending stock before implementing the EOQ model and after implementing the EOQ model. From the results of this comparison, it can be seen which order planning method is the most optimal to minimize losses on the company's holding costs. The comparison chart between the ending stock before the EOQ model is implemented and after the EOQ model is implemented can be seen below.

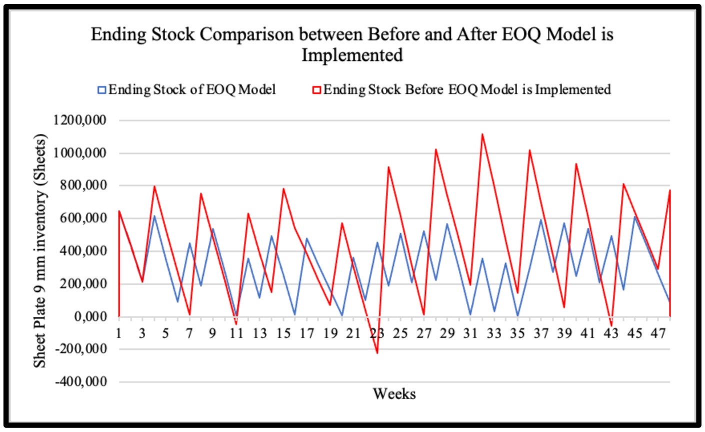

Figure 6. Ending Stock Chart Comparison between before and after the implementation of EOQ model.

From the chart, it can be seen that ending stock after the implementation of the EOQ model has a much smaller curve area than before the implementation of the EOQ model. It means that the holding cost incurred after the implementation of the EOQ model is lower than the holding cost before. In the ending stock chart after the implementation of the EOQ model, it can also be seen that there is no stockout so it can be concluded that the EOQ model's order quantity can fulfill the actual production demands. From the comparison of these charts, it can be said that the implementation of the EOQ model can reduce the amount of ending stock without stockout which means that it can reduce the company's holding cost and enable the company to meet all actual demand.

5.3 Proposed Improvements

With the result above, we propose improvement at PT X by implementing the EOQ Model in planning raw material orders. The implementation of the EOQ Model at PT X should be done by ordering 618 sheets of Steel Plate 9 mm for each order and the frequency of ordering is 21 times per year. With the improvement that we propose, PT X can have a profit of $ 604,535.64 more than before the improvement. However, this proposed improvement still needs further validation.

5.4 Validation

The result of comparison between the ending stock chart of before and after EOQ model implementation is validated using a statistical test. To measure the reduction of ending stock caused by the implementation of EOQ model, the difference between the ending stock of after and before EOQ model implementation is calculated as is shown by the table below.

Table 4. The difference between the ending stock of after and before EOQ model implementation

Difference between Ending Stock before and after the implementation of EOQ		
Week	Difference between Ending Stock (After - Before)	Absolute difference
1	0,000	0
2	0,000	0
3	0,000	0
4	-182,000	182
5	-182,000	182
6	-182,000	182
7	436,000	436
8	-564,000	564
9	54,000	54
10	54,000	54
11	54,000	54
12	-272,000	272
13	-272,000	272
14	346,000	346
15	-526,000	526
16	-526,000	526
17	92,000	92
18	92,000	92
19	92,000	92
20	-562,000	562
21	56,000	56
22	56,000	56
23	674,000	674
24	-725,000	725
25	-107,000	107
26	-107,000	107
27	511,000	511

Difference between Ending Stock before and after the implementation of EOQ		
Week	Difference between Ending Stock (After - Before)	Absolute difference
28	-797,000	797
29	-179,000	179
30	-179,000	179
31	-179,000	179
32	-760,000	760
33	-760,000	760
34	-142,000	142
35	-142,000	142
36	-723,000	723
37	-105,000	105
38	-105,000	105
39	513,000	513
40	-686,000	686
41	-68,000	68
42	-68,000	68
43	550,000	550
44	-649,000	649
45	-31,000	31
46	-31,000	31
47	-31,000	31
48	-685,000	685
Sample mean	-144,729	
Sample standard deviatio	370,560	
Sample median	-106,000	

The absolute difference between ending stock before and after the implementation of EOQ model are depicted on the following graph:

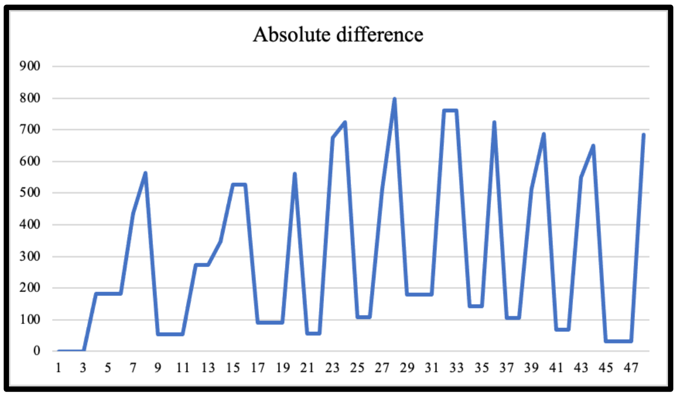

Figure 7. Graph of the absolute difference.

From the chart, it is concluded that the difference data does not follow a normal distribution. Each of the sample points also has autocorrelation with each other as it is a time series. Therefore, parametric statistical tests cannot be used. To compensate for the data quality, a non-parametric test is used for the statistical test. The test is conducted to determine whether the implementation of the EOQ model affects the amount of ending stock significantly. The non-parametric test that is used is the Wilcoxon One Sample Test. Wilcoxon One Sample Test is used to validate the null hypothesis and alternative (Walpole et al. 2011):

$$H0: \tilde{x} = 0 \text{ and } H1: \tilde{x} \neq 0$$

The Wilcoxon One Sample Test is then done using the IBM SPSS Statistics for Windows software (IBM Corp. Released 2011). The resulting output from the software is shown below.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The median of Difference_between_Ending_ Stock equals 0.00.	One-Sample Wilcoxon Signed Rank Test	.003	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 8. IBM SPSS Statistics for Windows output for Wilcoxon One Sample Test

Based on the P-value (asymptotic significance), it is concluded that implementation of the EOQ model significantly affects the amount of ending stock as the P-value is below the significance level (5%). It is also concluded that the effect of EOQ model implementation is the reduction of ending stock. This conclusion is based on the negative mean and median values of the difference between the ending stock before and after the implementation of the EOQ model is negative as is shown in Table 4.

6. Conclusion

With the assumption of not more than one week lead time, we identified economic order quantities of the raw material Steel Plate 9 mm that is aligned with PT X's technical constraint of using the MTO business production strategy. The results of analysis and calculation of order quantity using the EOQ model showed that the implementation of the EOQ model for order quantity planning in PT X can reduce the number of losses caused by holding costs. However, the decrease of holding cost also means there is a higher ordering cost. In the case of PT X, the increase experienced by ordering costs is not greater than the decrease in the amount of holding costs. Therefore, at the end of the calculation, it is concluded that the implementation of the EOQ model for order quantity planning delivered a higher profit. This is proven through the validity test using the Wilcoxon One-Sample Test. From the results of the validation test, it is proven that the implementation of EOQ reduces the ending stock of PT X which also means a reduction of its holding cost and an increase of its profit. Therefore, we can conclude that MTO companies can reduce their inventory cost through reducing their holding cost by implementing the EOQ model.

This study was completed with various constraints. The main research constraint is constraint regarding the supplier limitations of only being able to do shipment once a month. To make the implementation of EOQ model to MTO businesses more practical, it is suggested to do further research about development of an EOQ model that can consider this shipment constraint. The research has also identified an opportunity for improvement that can be researched further if PT X changes its supplier of raw materials to a supplier that does not have such constraints. Hence, further research to improve PT X's inventory management and control can be done by implementing more novel theoretical EOQ models.

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