

RESEARCH PROJECT REPORT

Inventory Analysis for a Make-to-Order (MTO) Manufacturer

by

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Submitted to the MIT Malaysia Supply Chain Management Program in Partial Fulfillment
of the Requirements for the Degree of

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ABSTRACT

The project studies the raw materials inventory management of a Make-to-Order (MTO) air filtration company to identify the issues faced and potential improvements in inventory management to unlock the working capital while maintaining the Cycle Service Level (CSL). We use Inventory Turn (IT), Cash Conversion Cycle (CCC), and Gross Margin Return on Investment (GMROI) to measure the performance of the company by comparing those measures against other industry players. We conduct Demand and Supply Variability Analysis to identify where variability may come from. Subsequently, we narrow down the product groups with high volatility for further investigation. We compare the Total Inventory Relevant Cost and average annual inventory value of the current inventory policy with Periodic Review policy (R,S) and Continuous Review Policy (s,Q). Our research shows that the case company has high volatility in Demand variability, and its current inventory policy resulted in high safety stock requirement. With Periodic Review Policy (R,S), we are able to achieve a 25% reduction in average inventory value and 35% savings in Total Inventory Relevant Cost across three years. We recommend the case company perform further analysis of Periodic Review Policy for all its raw materials of product group A1 and A2, then switch over to this inventory model if the model can achieve substantial savings.

Research Report Supervisor: Dr. Javad Feizabadi

Title: Associate Professor

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1 Introduction

1.1 Introduction to the company

1.1.1 Background

The case company is a key leader in the global air filtration industry with half-of-century clean air expertise, more than four thousand employees, generating USD 860 million annual revenue, thirty manufacturing sites, five Research and Development (R&D) centers, and twenty sales offices footprint. The company's vision is to make clean air a human right, just like clean water, while the mission is to protect the environment, people, and process by defining, developing, and delivering filter solutions that provide clean air with energy efficiency.

The figure below shows the global sales offices and production units.



Figure 1: Global Sales Offices and Production Units

1.1.2 Business Areas

The company has four business areas which are Filtration Solutions (HVAC), Power Systems, Molecular Contamination Control (MCC), and Air Pollution Control (APC).

- a) Filtration Solutions, like HEPA – Providing air handling units and filter supplies to ensure clean air, free of harmful pollutants, dust and dirt, allergens, and contaminants.

- b) Power Systems (PS) - Providing Air inlet for acoustical systems for turbo machinery, including gas turbines, generators, and compressors.
- c) Molecular Contamination Control (MCC) - Providing molecular filtration solutions to filter out harmful gases as well as odors and chemicals present in gaseous form, which could cause corrosion in equipment.
- d) Air Pollution Control (APC) - Providing industrial dust, fume, and mist collectors for achieving a clean environment.

1.1.3 Make-to-Order versus Make-to-Stock Environment

A company has to determine its production strategy in a manufacturing environment, whether to adopt a Make-to-Order (MTO), Make-to-Stock (MTS), or sometimes a hybrid strategy. The crucial factor that influences the production strategy is the availability of the demand information at the stage of production – do we have the information readily available, or we need to rely on forecasted information? In supply chain management, we always talk about three flows, i.e., the information flow, material flow, and money flow. In a Make-to-Order environment, the demand information (information flow) is firmed and available. The production will start upon receiving a customer's order, turning raw materials or sub-components into finished products (material flow). In a make-to-stock environment, the demand information is not available, and production orders are based on the result of production planning using a sales forecast. Inventory holding of the finished product is required to fulfill unknown future demand. In the MTS environment, we have to trade-off between material flow with information flow, i.e., by producing and carrying finished goods inventory upfront to fulfill unknown demand. However, in a Make-to-Order environment, the information flow is known, and hence we can delay the production till known orders are received. This situation is known as postponement, and we only need to manage the inventory as raw materials instead of finished products.

In the MTO environment, the importance of inventory management is to ensure we can supply raw materials timely for the production of finished products and deliver against our promise to the customer, namely achieving the target cycle service level. Thus, depending

on MTO / MTS strategy, it has a significant implication to inventory model and hence working capital tied up in operations.

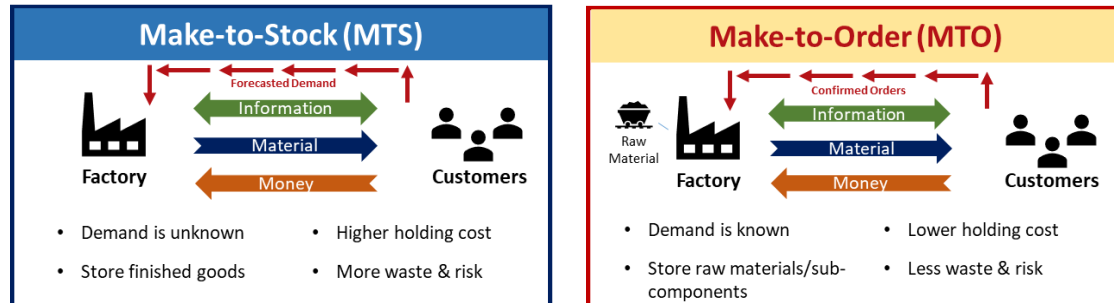


Figure 2: Difference of Make-to-Order versus Make-to-Stock Environment

1.1.4 Products

Industrial air filters are devices designed to remove solid particulates and molecular contaminants for the purpose of improving air quality in a system or environment (Engineering 360 Powered by IEEE GlobalSpec, n.d.). Air filters typically consist of a sturdy frame filled with some type of filter media, which is sealed to prevent leaks between the frame and media. Some filters may also have a face-guard — a screen attached to the filter to protect the media during handling - or a gasket to prevent leaks between the filter frame and its housing. The figure below illustrates these components on a typical air filter consisting of frame, gasket, and media.

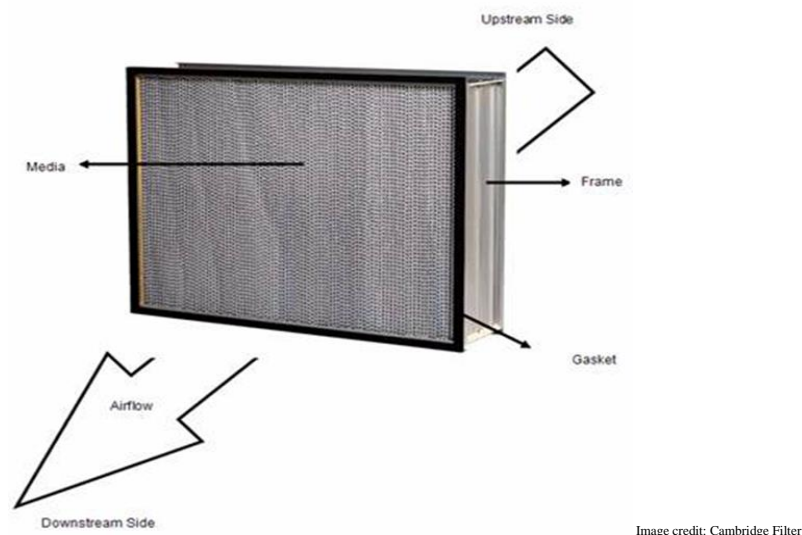


Figure 3: Component of Typical Air Filter

The company maintains a product catalog with standard products that they will produce in a Make-to-Order environment. Occasionally, the company will get some customized order requests. Unlike a make-to-stock environment where inventory management challenges are with finished products, the Make-to-Order environment pushes the inventory challenges upstream, i.e., the management of raw materials inventory. All raw materials must be readily available for production when customer orders are received in order to meet the target cycle service level. The typical lead time to import raw materials required by the case company is one week to three months. Balancing inventory holding, thus capital tied up versus meeting cycle service level, is a challenging task.

In addition, there are further challenges in raw materials inventory management caused by product variances. To illustrate this, we select the High Flow Series product as an example consisting of up to forty variations, as displayed in the figure below. More variations in the finished product will result in more raw material requirements, thus increasing the working capital tied up in inventory management.

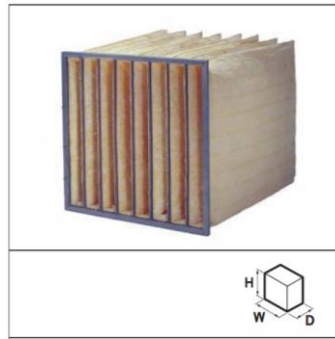


Figure 4: High Flow Series Product

Number of Pockets	Nominal Size (Height x Width x Depth, inches)	Rated Airflow (Cfm)	M14 Initial Resistance (inches w.g)	M13 Initial Resistance (inches w.g)	M11 Initial Resistance (inches w.g)	M9 Initial Resistance (inches w.g)	Media Area (sq.ft.)
12	24 x 24 x 32	2500	0.54	0.4	0.27	0.21	129
9	24 x 20 x 32	1875	0.54	0.4	0.27	0.21	97
6	24 x 12 x 32	1250	0.54	0.4	0.27	0.21	65

9	20 x 20 x 32	1575	0.54	0.4	0.27	0.21	81
12	24 x 24 x 15	1500	0.49	0.34	0.21	0.15	58
9	24 x 20 x 15	1100	0.49	0.34	0.21	0.15	44
6	24 x 12 x 15	750	0.49	0.34	0.21	0.15	29
9	20 x 20 x 15	950	0.49	0.34	0.21	0.15	37
10	24 x 24 x 30	2400	0.69	0.46	0.29	0.22	101
8	24 x 20 x 30	1900	0.69	0.46	0.29	0.22	81
5	24 x 12 x 30	1200	0.69	0.46	0.29	0.22	50
8	20 x 20 x 30	1625	0.69	0.46	0.29	0.22	68
10	24 x 24 x 22	1750	0.54	0.36	0.22	0.15	73
8	24 x 20 x 22	1400	0.54	0.36	0.22	0.15	58
5	24 x 12 x 22	875	0.54	0.36	0.22	0.15	36
8	20 x 20 x 22	1175	0.54	0.36	0.22	0.15	49
8	24 x 24 x 36	2400	0.69	0.46	0.29	0.22	97
7	24 x 20 x 36	1900	0.69	0.46	0.29	0.22	85
4	24 x 12 x 36	1200	0.69	0.46	0.29	0.22	49
7	20 x 20 x 36	1625	0.69	0.46	0.29	0.22	71
8	24 x 24 x 30	2000	0.60	0.40	0.25	0.18	81
7	24 x 20 x 30	1750	0.60	0.40	0.25	0.18	70
4	24 x 12 x 30	1000	0.60	0.40	0.25	0.18	40
7	20 x 20 x 30	1450	0.60	0.40	0.25	0.18	59
8	24 x 24 x 22	1750	0.57	0.38	0.24	0.17	58
7	24 x 20 x 22	1500	0.57	0.38	0.24	0.17	51
4	24 x 12 x 22	875	0.57	0.38	0.24	0.17	29
7	20 x 20 x 22	1300	0.57	0.38	0.24	0.17	43
6	24 x 24 x 36	1750	0.54	0.35	0.21	0.15	76
5	24 x 20 x 36	1500	0.54	0.35	0.21	0.15	63
3	24 x 12 x 36	875	0.54	0.35	0.21	0.15	38
5	20 x 20 x 36	1225	0.54	0.35	0.21	0.15	53
6	24 x 24 x 30	1750	0.56	0.37	0.23	0.16	63
5	24 x 20 x 30	1500	0.56	0.37	0.23	0.16	52
3	24 x 12 x 30	875	0.56	0.37	0.23	0.16	31
5	20 x 20 x 30	1225	0.56	0.37	0.23	0.16	44
6	24 x 24 x 22	1750	0.71	0.46	0.07	0.18	45
5	24 x 20 x 22	1500	0.71	0.46	0.07	0.18	38
3	24 x 12 x 22	875	0.71	0.46	0.07	0.18	23
5	20 x 20 x 22	1225	0.71	0.46	0.07	0.18	32

Table 1: High Flow Series Technical Specification

1.1.5 Malaysia Plant

The company has set up four manufacturing plants in the Asia region - Malaysia, China, India, and the Middle East as per the map in Figure 5. The plant in Malaysia (the case company in this research) is the largest and is the global hub in Asia that can export its products to all sales offices over the world, thanks to the strategic location in the heart of Southeast Asia, while the other three plants cater only to the local markets. The case company has annual revenue growth of approximately 10% year on year (YOY) from 2016 onwards. However, it is also reported that the company faces the challenge of excessive raw materials inventory growth. In 2018, its annual revenue was approximately MYR 185M (approximately 24% growth from 2015), whereas its inventory holding of raw materials grew excessively, as illustrated by the growth of 123% in inventory value (from MYR 11,028,293 in Dec 2015 to MYR 24,590,555 in Dec 2018). The actual annual consumption value of raw material was only 50% of the average value of raw material inventory. Malaysia Management realizes the high raw material inventory value ties up the overall company working capital. This situation poses an internal survivor issue where Malaysia Plant is becoming less attractive to the Group Management with low ROI than other Asia Plants. As a result, there is a risk that Group Management changes its global hub to other more competitive plants.



Figure 5: Asia Plants Location

While inventory planning is performed at the plant level, all raw material sourcing is done at the group level from Europe to control quality. The payment term to suppliers is 30 – 60 days. All raw material imports are based on Ex-Works and take an average of 1 week to 3 months to arrive at the case company's warehouse.



Figure 6: Raw Material Procurement Process

The company's target Cycle Service Level (CSL) for its Make-to-Order production is as below.

Product Category	Target CSL	Lead Time
A1	90%	4 days
A2	90%	6 days
B	90%	8 days

Filters are required to change at the end of lifecycles to ensure functionality - the fewer the filter changes, the better from a maintenance and cost savings perspective. Table 2 shows the general lifecycles of different types of filters.

Types of filters	Lifecycle
Pre-filter	refresh required in 3 to 6 months
Secondary filter	refresh in 10 to 12 months
HEPA filter	refresh in 5 to 15 years

Table 2: General Lifecycle for Different Types of Filters

The order placing process for Malaysia Site is illustrated in Figure 7 below.

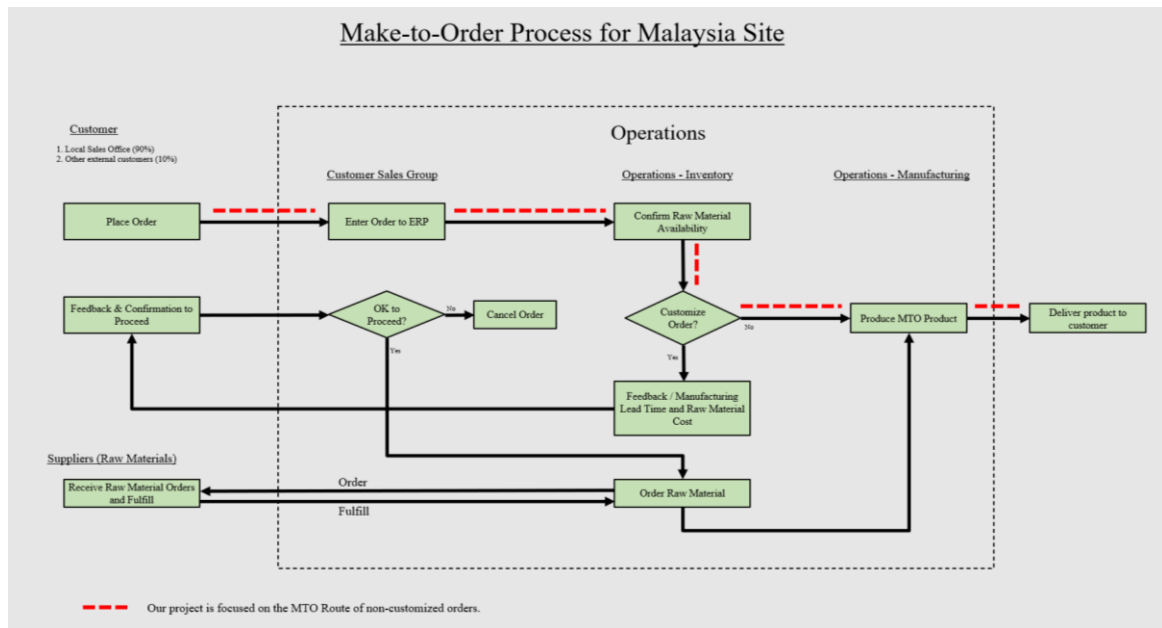


Figure 7: Make-to-Order Process for Malaysia Site

1.2 Problem Statement

Being a global hub, the case company must keep enough raw material in stock in order to meet the target CSL of its MTO production. However, besides facing external competition with its competitors, the case company faces the challenge of potentially losing its global hub position within the Group due to high working capital tied up in operations, where one of the contributing factors could be high raw material inventory holding. Hence, the Vice President of Supply Chain must confirm the issue and identify the potential solution(s) that can improve the situation faced by the case company.

1.2.1 High raw material inventory growth against much lower sales growth

The case company manufactures air filters that are sold to the company sales office globally. It procures and stores all its raw materials at its warehouse in Malaysia to ensure smooth and timely production. As of December 2018, the company's Month-To-Date (MTD) raw material inventory stood at MYR 25 million, whereas the value of raw materials consumed was only MYR 10 million. Raw material inventory value started with MYR 11 million in December 2015 and jumped up to MYR 25 million in December 2018, which was 123% growth, while the sales growth deduced from Cost of Goods Sold (COGS) was only 24%.

MTD Period	Raw Material Inventory (MYR)	Raw Material Inventory + / -	Actual Raw Material Consumption (MYR)	Actual Raw Material Consumption + / -	COGS (MYR)	COGS + / -
Dec 2015*	11,028,293	N/A	N/A	N/A	99,923,894	N/A
Dec 2016	14,319,504	+ 29.8%	7,527,638	N/A	100,653,104	+ 1.0%
Dec 2017	15,154,138	+ 5.8%	7,964,300	+ 5.8%	108,890,783	+ 8.18%
Dec 2018	24,590,555	+ 62%	10,163,496	+ 27.63%	124,448,821	+ 14.29%
Growth from 2015 - 2018	123%				Growth from 2015 - 2018	24%

*Dec 2015 data was derived based on the beginning raw material inventory of Jan 2016 in their annual report.

Table 3: Raw Material Inventory and Cost of Goods Sold 2015 - 2018

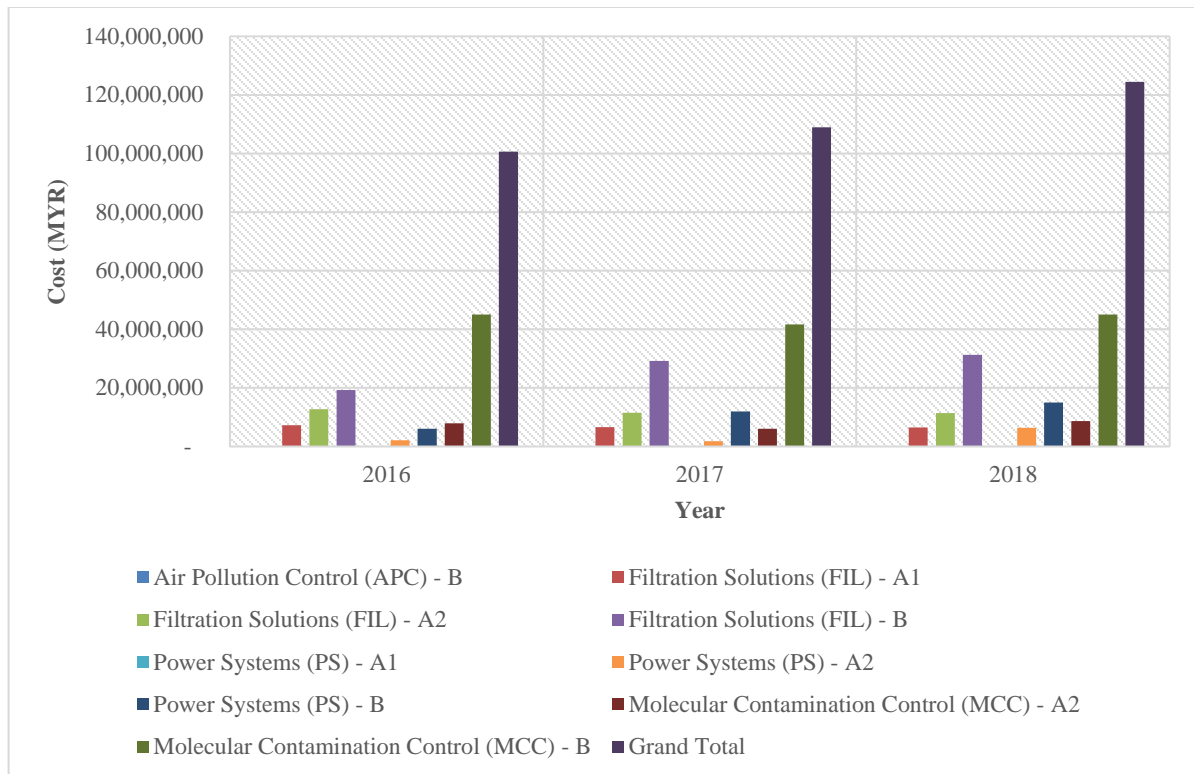


Figure 8: Cost of Goods Sold by CSG Group 2016 - 2018

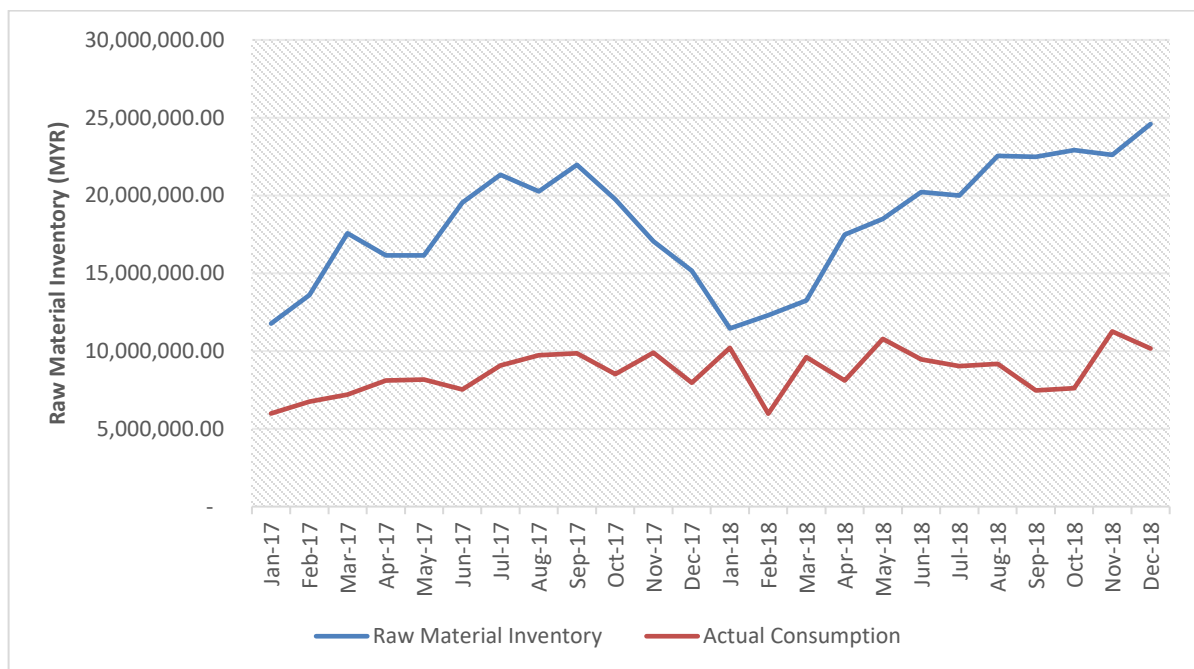


Figure 9: Raw Material Inventory Against Actual Consumption

We observe that one of the key raw materials used in producing air filters is aluminum where it is used to make frames to hold the air filters. We wonder whether there was hedging involved; however, from the discussion with key personnel, there was no effort in hedging because the case company procured manufactured aluminum frames of various sizes from suppliers. The case company does not procure aluminum as raw commodity materials. In other words, the suppliers could hedge aluminum, but not the case company. The current average raw materials inventory turnover days are 72 days.

1.2.2 Why is there a mismatch in the sales vs. inventory growth?

The value of raw materials inventory is increasing quarter over quarter, while COGS remain relatively constant. Inventory value growth was 123% from 2015 to 2018, whereas the sales growth was only 24%. What causes the mismatch between inventory holding growth vs. sales growth? The significant growth of inventory holding is locking up working capital, which could be used to fund expansion in China. Some of the reasons given by staff for the problem mentioned above are:

- a) Long lead time for raw material procurement
- b) Suppliers minimum order quantity (MOQ) requirement
- c) Slow-moving materials
- d) Inaccurate sales orders (resulted in order cancellation by sales offices to the case company)

The four general categories of raw materials (which have different grades) are:

- a) Media, like fiberglass
- b) Frames, like metal, plastics, and aluminum
- c) Glue
- d) Hot melt, which is an adhesive to hold the filter together.

In this research, our objectives are:

- 1) Examine the case company MTO supply chain whether it is facing inventory management issue that causes high working capital tied up

2) Propose appropriate recommendations to the case company to improve their current situation.

1.3 Introduction to the industry

1.3.1 Global air filters industry overview

Fortune Business Insights (2019) states that the global air filters market size, currently stands at USD12.10 billion in 2019, is projected to reach USD20.63 billion by 2027, exhibiting a CAGR of 6.9% during the forecast period. The key drivers of the growth include more stringent government regulations on environmental safety and health and rapid industrialization, which drive up the industrial air filtration market (2021).

The automotive sector is another industry that has a high demand for air filtration solutions. According to Global Air Filter Market 2018-2022 (2018), the growth of the automotive sector is also expected to drive air filter market growth in the forthcoming years. The automotive industry is the primary end-user to this market, and automobiles powered by fossil fuels need to equip with cabin air filters and engine air filters. Cabin air filters remove potentially harmful particles entering the cabin, and the engine air filter restricts their entry into engine cylinders.

The growing demand for washable and reusable filters will be a significant trend and is gaining prominence in the air filter market during the next few years. Reusable filters provide high indoor air quality and offer a minimum contribution to landfills. Moreover, these washable air filters prevent microbial growth and are suitable for wet environment applications. With the rising consumer preference for green alternatives and more stringent government regulations, the utilization of these filters is likely to surge during the forecast period.

1.3.2 Not unusual to the industry

Holding high raw material inventory is a common challenge to all Make-to-Order (MTO) industries as they need to balance between raw material availability for production versus

meeting the target CSL to the customer. However, with the proper information flow and good supply chain planning, a Make-to-Order company can fulfill its customer orders within target CSL with just enough raw materials inventory holding, thus akin it to unlock colossal working capital.

1.4 Relevant literature

1.4.1 List of related literature

Several literature reviews shared about the inventory management, information sharing, performance measurement, and optimization approaches related to our topic as the list below.

1. A Simulation-Based Approach To Inventory Management In Batch Process With Flexible Recipes. (2013). Proceedings of the 2013 Winter Simulation Conference.
2. A, A.-R., & GA, D. (1998). Make-to-Order versus make-to-stock in a production-inventory system with general production times. *IIE Trans* 30(8), 705–713.
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<https://corporatefinanceinstitute.com/resources/knowledge/accounting/cash-conversion-cycle/>
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1.4.2 Mature Literature

The current state of the literature is mature. Hence, we should be able to improve the raw material inventory level for the case company in the air filtration industry.

1.5 Motivating question

1.5.1 Motivations

We spend 60% to 90% of our time indoors, either in the workplace, restaurant, or at home stated by Marios, Apostolos, & Panayotis (2011). Indoor air can be 50 times more polluted than outdoor air. An estimated 50% of illnesses are caused by poor indoor air quality.

Improvement of indoor air quality in the workplace can increase productivity by up to 10%.

We strongly believe that clean air is a human right that drives us to work on this exciting research project.

All Make-to-Order (MTO) manufacturers will face excessive raw material inventory challenges regardless of food, industrial manufacturing, pharmaceutical industry, and other sectors. In view of the case company (Malaysia's Plant) surviving challenges with the risk of closing down, we are intent on helping them understand their supply chain and its raw material issue and propose a sound solution to improve the situation. Furthermore, when doing the research, we noticed that the growth of the air filtration industry is so tremendous, and clean air is so important to humankind. This situation further energizes us to work on this research project.

1.5.2 Research questions

Our research is aimed to find out the answers to the following questions:

- 1) Why is there a mismatch between the raw materials inventory growth vs. the sales growth?
- 2) What is the right solution to improve the situation?

2 Literature Review

Whether it is a Make-to-Order (MTO), Make-to-Stock (MTS), or Assemble-to-Order (ATO) manufacturing process, inventory optimization has a significant impact on working capital and revenue generation. The form of inventories to be dealt with may be different. In MTO/ATO environment, we mainly hold raw materials or WIP inventory, whereby in the MTS environment, we mainly hold finished goods inventory. The following review of the literature confirms that there are many challenges in inventory management faced by manufacturers in different manufacturing environments from various industries, ranging from availability of demand information for good inventory planning, different inventory policies or models, and many other factors such as lead time, demand and process time variability. In the MTO environment, it is crucial to improve raw material inventory holding to be able to fulfill customer orders within the target CSL. Otherwise, the company will either keep too high inventory, thus capital tied up, or risk of not meeting target CSL and losing its customers.

2.1 Inventory model and supply chain coordination

Hau L. Lee (1996) raises the challenges faced by an operational manager due to product proliferation. Logistic issues like inventory and service are thus critical dimensions that design engineers should consider, in addition to measures like functionality, performance, and manufacturability. This paper describes how some simple inventory models can be used to support the logistic dimensions of product/process design. It will be the point of considerations for our analysis later to build a suitable inventory model and compare it with the existing inventory model for inventory performance analysis to support logistic dimensions of product or process design in a Make-to-Order environment for the air filtration industry.

Brian, Linda, Alan, & Antoniode (1996) state that Make-to-Order companies are in the business of supplying products in response to customer orders in competition with other companies, based on price, technical expertise, delivery time, and reliability in meeting due

dates. Dealing correctly with inquiries is the major problem that MTO companies face. A lack of coordination between sales and production at the customer inquiry stage often leads to confirmed orders being delivered later than promised or being produced at a loss due to raw materials unavailability.

Matthias & Frits (2008) state that supply-chain coordination relies on the availability of timely and accurate information visible to all actors in the supply chain. However, new demands on the supply-chain system require changes to information flow and exchange. They undertake a case study of three automotive supply chains that face such new demands resulting from the introduction of an order-driven supply-chain strategy. Availability of demand information during the production stage will impact the production strategy and hence its inventory model. In our research, we will study the impact of the inventory model on raw materials in the MTO environment of the air filtration industry.

We believe that both the inventory and supply chain coordination elements are essential elements for raw material inventory improvement. In our case, the sales orders are provided by the local sales offices and are subsequently entered by the Customer Sales Group (CSG) into the ERP system upon checking the raw material inventory availability. Therefore, up-to-date and optimal raw material inventory will bring advantages for the company. We will evaluate different inventory models' performance, knowing the lead time of raw materials supply with the target CSL to be fulfilled. Hopefully, we can find some improvements from this research.

2.2 Inventory optimization

He, Jewkes, & Buzacott (2002) examines several inventory replenishment policies for a Make-to-Order inventory–production system that consists of a production workshop and a warehouse. According to a Poisson process, demands arrive at the production workshop and are processed in a First-Come-First-Serve (FCFS) manner. The production workshop requires that the warehouse provides, as needed, raw materials for use in the production process. The warehouse inventory is replenished according to an inventory replenishment policy. The optimal replenishment policy, which minimizes the average total cost per

product, is derived using a Markov decision process approach. The structure of the optimal replenishment policy is explored. Simple "order-up-to," "myopic," and heuristic replenishment policies were introduced. The myopic and heuristic replenishment policies are easy to compute and yet perform almost as well as the optimal replenishment policy. Our project will explore different inventory replenishment policies based on the historical demand data to evaluate the results and implications to inventory holding costs for the air filtration industry. We will also analyze and validate the distribution of our raw materials demand (based on firmed orders in the past) that could impact our inventory holding of raw materials. As long as there is a reasonable amount of saving from the research, we can suggest the solution to the case company.

Hopp, W. J. & Spearman, M. L.(1999) state that the efficient utilization of labor, material, and equipment is essential to keeping costs competitive. The quality revolution of the 1980s served to focus attention on internal quality at each step in the manufacturing process and its relationship to customer satisfaction. Lastly, responsive delivery without inefficient excess inventory requires short manufacturing cycle times, reliable processes, and effective production planning and inventory planning and management, and tight integration across many functions such as sales, production, and inventory are crucial. Our case company in Malaysia does not procure raw material directly. It procures raw material via the central procurement group at the group level based in Europe to achieve economies of scale as well as to control the quality of raw materials procured. Quality is critical in the air filtration industry. All filter media has to meet high technical specifications. All the aluminum frames have to be cut into precise dimensions to ensure a tight fit. We will examine how raw material lead time may impact the inventory holding cost of our case company.

Do Young Jung, Seung Heon Han, Keon Soon Im, and Chung Kyu Ryu (2007) examine that there are usually plenty of material inventories in a construction site. More inventories can meet unexpected demands, and also, they may have an economic advantage by avoiding a probable escalation of raw material costs. They found that, under uncertain project conditions, keeping higher inventory would minimize financial loss due to materials unavailability, thus impacting production progress, avoiding materials cost escalation due to

last-minute rush demand. It may reduce the average inventory cost for the project. This concept is similar to considering the potential stock-out cost in computing the Total Inventory Relevant Cost comparison while evaluating inventory policies. We will try to apply these findings to our research.

2.3 Balancing between Ordering Cost and Inventory Holding Cost

Masoud Rabbani, Negin Bagherzadeh, Hamed Rafiei (2014) examine the role of inventory in a hybrid Make-to-Stock (MTS)/Make-to-Order (MTO) production environment, based on a case study performed in a fruit juice company. In their research, demands for Finished Good (FG) inventories follow a normal distribution. They propose a model to calculate economic order quantity (EOQ) by obtaining demands for Raw Material (RM) inventories through Work-in-process (WIP) and FG inventories. For the validity of their claim, they illustrate some samples of products on different days and compare them with the old estimation method of WIP and EOQ. In our research, we will calculate the mean and standard deviation of raw material demand in an MTO production environment for an air filtration company using past years' production orders. The historical demand pattern of raw materials consumption will be fitted with @Risk software to find out its distribution. This analysis will explore the inventory management and holding cost using various inventory models and compare.

Ms. S.M.Samak-Kulkarnia, Dr.Mrs.N.R.Rajhans (2013) presses a model for determining the ordering policy, minimizing the total inventory cost. They claimed that ordering in the right quantities at the right time is always a crucial issue as demand is uncertain and difficult to forecast. This paper considers various models such as lot by lot size, economic order quantity, periodic order quantity, least unit cost, least total cost, least period cost, Wagner-Whitin algorithm, etc. Total annual inventory costs for various items are calculated by each method. Typically, when we claim that the inventory cost is high in a company, many people focus only on the average inventory value as registered in the accounting system. They draw a conclusion that inventory value is escalating when they see a trend of increase. However, besides average inventory value, it is also crucial to evaluate the Total Inventory Relevant Cost (TRC) when assessing inventory policies and performance. Total Inventory

Relevant Cost consists of 3 cost components: the Ordering Cost, the Inventory Carrying Cost, and the Pipeline Inventory Carrying Cost. We need to optimize the Total Inventory Relevant Cost by striking a balance among the order frequency, the amount to procure per order, and the quantity to hold in stock. In our research, we plan to examine and compare the Total Inventory Relevant Cost for the current inventory policy used by the case company against two other policies, the Periodic Review Policy (R,S) and the Continuous Review Policy (s,Q).

From the literature above, we know that having optimal quantities of each kind of inventory and controlling them is one of the most important goals of any organization to minimize cost and maximize profit. Thus, it is always crucial for any manufacturing organization to lower the Total Inventory Relevant Cost in inventory management by choosing adequate inventory policies for managing different types of inventory. The policies decide on when inventory should be replenished, how much to order per replenishment, how much safety stock to carry to buffer for uncertainties. The goal of an organization is to achieve minimum Total Inventory Relevant Cost and low average annual inventory value while still being able to fulfill customer demand as per the target Cycle Service Level.

2.4 Demand and Supply Variability, GMROI and Measurement

Olhager, J. (2003) states that the order penetration point (OPP) defines the stage in the manufacturing value chain where a particular product links to specific customer orders. Different manufacturing environments such as make-to-stock (MTS), assemble-to-order (ATO), Make-to-Order (MTO), and engineer-to-order all relate to different positions of the OPP. The significant factors are demand volume and volatility and the relationship between delivery and production lead times. We will select at least one product family with a high variability of size and apply the concept of this research to validate for the air filtration industry. Demand variability and supply variability analysis will be performed to determine which product group to dive deep into for further analysis.

Raman, Gaur, & Kesavan (2006) explore the relationship between the retailer's inventory and future earnings; the relationship between inventory level and stock price. The company

with high inventory may not be doing good due to the high chance of markdown. The case used the gross margin return on inventory investment (GMROI) model to evaluate company performance. GMROI is an inventory profitability evaluation ratio that analyzes a firm's ability to turn inventory into cash above inventory cost. It is calculated by dividing the gross margin by the average inventory value and is used often in the retail industry. We plan to extract several public listed companies' data, from the air filtration industry, from their annual reports for our research to compute the GMROI measure to evaluate the inventory performance result. Companies within the same segment can then be compared using GMROI to measure their inventory performance. GMROI represents a better performance indicator than Inventory Turn as GMROI will normalize the effect of SKU profit margin.

Chandra & Tully (2016) proposes a raw material inventory policy evaluation tool that allows a company to understand how certain key performance indicators are affected by various changes in its inventory policy and helps the company devise a strategy. This evaluation tool can then guide the company towards a better inventory policy in the absence of cost information and shows the results in several events. Our research will use Excel to develop an evaluation tool to calculate the reorder quantity, reorder level, cycle stock, safety stock, and pipeline inventory while maintaining the targeted Cycle Service Level (CSL) using historical demand data. Then, we simulate the results using different inventory policies and compare the Total Inventory Relevant Cost and the average annual inventory holding value to identify potential cost-saving opportunities.

The market size of the air filtration industry will continue to grow, while Asia-Pacific is the fastest-growing market for industrial gases. Fortunately, there are many general methods and approaches for raw material inventory improvement to adapt and apply to the air filtration industry. Reflecting on that maturity, the literature reviewed in this report defines the overall problem and offers some solutions. Nevertheless, further research is needed to develop a better model to investigate the effect of keeping lower raw material inventory based on product decisions between different groups of raw material categories and recommendations to MTO inventory policymakers.

3 Research Method

Our project adopted a case study approach to examine the contemporary phenomenon and triangulate with company historical data, direct observations, face-to-face meetings, and online public data to answer the research questions. A quantitative research method was used to calculate the Inventory Turn (IT), Cash Conversion Cycle (CCC), and Gross Margin Return on Investment (GMROI) for the case company and its competitors within the industry for comparison of company performance. We also performed Demand and Supply Variability Analysis, ABC Analysis, Cycle Service Level Analysis to evaluate the case company performance. Lastly, we compare the case company's current inventory policy against two other inventory policies, the Periodic Review Policy (R,S) and Continuous Review Policy (s,Q) model, on the respective Total Inventory Relevant Cost and average inventory value.

3.1 Research setting

The company is a multinational air filtration manufacturer headquartered in Europe with multiple factories in the Asia region. The plant in Malaysia (the case company) is identified as facing survival issues due to high raw material inventory and lost competitive advantages to the sister companies in the region. In the first phase, our analysis relied on the Cash Conversion Cycle (CCC), Inventory Turn (IT), and Gross Margin Return on Investment (GMROI) to evaluate the inventory performance of the case company against industry players. To understand whether the case company was facing an inventory problem, we did not rely on IT; we chose GMROI as it normalized the effect of SKU profit margin.

In the second phase, demand variability and supply variability analyses were performed on A1, A2, and B items to check the volatility of demand (Order Quantities) and supply (production lead time). In addition, we performed an ABC analysis to validate the financial contribution of the SKUs. Subsequently, we analyzed the ability of the case company to meet the quoted Cycle Service Level (CSL) for delivery lead time.

Lastly, we examine the effectiveness of the case company inventory policy against the Periodic Review Policy (R,S) and Continuous Review Policy (s,Q). It will allow us to compare the Total Inventory Relevant Cost and average annual inventory value with their current inventory policy to observe the opportunity for cost savings for a Make-to-Order (MTO) manufacturer in the air filtration industry.

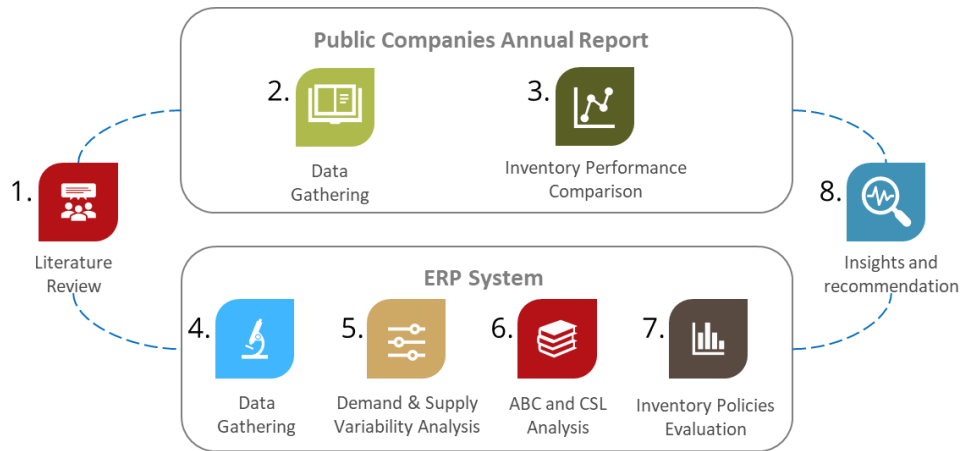


Figure 10: Research Direction and Methods Used

3.2 Data collection

We collected data related to our research project from the case company, which included the Sales information from Customer Service Group (CSG), Inventory and Stock Aging information from Finance Department, Production Status Dashboard, Historical Work Order production, and raw material consumption from IT Department, Bill of Materials information, and machine downtime information. The description of each material has been summarised in Table 4 below.

Material	Department	Description
Sales Statistic	Customer Service Group (CSG)	Sales information by Business Unit, CSG Group, Quantity, Cost, and Type of sales.
Inventory	Finance Department	Raw material inventory value and actual raw material consumption.
Stock Aging	Finance Department	Stock aging from 12-24 months and over 24 months.

Production Status Dashboard	IT Department	Product status for each work order with the header value such as Work Order No., Work Order Release Date, Production Start Date, Production End Date, Work Order Close Date, Required Quantity, Debtor, Debtor Name, Sales Order Number, Article Number, Article Description, Invoice Number, Shipment Date, and Status.
Work Order report with Raw Material consumption	IT Department	Work Order Raw Material worksheet consists of 1,048,575 rows of records with the header value such as Work Order No. Article No, Article CSG Group, Work Order Quantity, Component Stock Code, Component Required Quantity, Scrap Factor, Total Component Required Quantity, Total Component Quantity+Scrap Factor, Component Unit of Measurement, Product Group, and Component CSG Group.
Bill of Material (BOM)	Logistic Department	BOM info with BOM Type, Item Code, Item Description, Component, Component Description, Warehouse, Required Quantity, Unit of Measurement, Total Required, Free Stock, Balance, PO Quantity, Lead Time, Arrigo, Date, Component Standard Cost Price, Unit of Measurement from Manufacturer and Quantity.
Inventory Dashboard	Logistic Department	Raw material status with Stock Code, Description 1, Description 2, Unit, Leadtime, Arrigo, and Standard Cost Price (SCP)
Raw Material Consumption	Logistic Department	Raw material consumption detail with Article Number, Description, Unit of Measurement, Standard Cost Price, Transaction Count, Total Transaction, Quantity Issued, Arrigo and Total value break down by every month.
Raw Material Report	Logistic Department	Raw material inventory with Stock Code, Description 1, Description 2, Unit, Warehouse Shelf Stock, Total Reserved Stock, Sum of Actual Reserved, Free Stock, PO Quantity, Lead Time, Safety Stock, Safety Stock + 1 lead time, Consumption / Day, Arrigo, ReOrder Level, EOQ, and SCP.
CFM Loading	Production Department	Total loading per day/per line
KPI	Production Department	Machine downtime info such as average MTBF (Hour) % and MTTR (Hour) %
Material Variance	Production Department	Material usage variance info

Table 4: Description of Document Material Provided by the Case Company

3.2.1 Data source from ERP System

Initially, we studied all the files provided that covered the raw material consumption from 2016 – May 2019, sales statistics broken down by business unit from 2016 – May 2019, and work order info from 2016 to 2019. We choose data from 2016 to 2018 only as the full-year data is provided when analyzing the data.

Data mapping across different excel files is performed by introducing ProductCode and RawMaterialCode. Then, data cleansing is performed with the process of parsing, correction, standardizing, matching and consolidation. Besides that, we build a ProductCode dictionary to ease cross-referencing.

3.2.2 Data source from Public Companies Annual Report

We use Public Data downloaded from the annual reports of industry key players' websites such as Parker-Hanriffin Corporation, Donaldson, Colfax Corporation, Ahlstrom Munksjo Oyj, Lydall Inc, Lindab International AB, CECO Environmental Corp, and Nederman Holding AB. From the annual reports, we extract key financial information to calculate CCC, IT, and GMROI. The currency converted to USD based on the review date exchange rate if the annual report used a different currency.

3.3 Data Analysis

Analyses were done with inventory reports exported from iScala ERP as furnished by the case company. We used Microsoft Excel with PowerPivot and @Risk as the tools for data analysis.

3.3.1 CCC and IT Analysis

"The Cash Conversion Cycle (CCC) formula is aimed at assessing how efficiently a company is managing its working capital", Corporate Finance Institute (2020). Below is the formula that we used for the CCC calculation.

Cash Conversion Cycle (CCC) = days receivable/sales outstanding (DSO) + days inventory outstanding (DIO) – days payable outstanding (DPO).

$$\text{DSO (days)} = \frac{\text{Starting AR} + \text{Ending AR}}{2} \div \frac{\text{Revenue}}{365}$$

$$\text{DIO (days)} = \frac{\text{Starting Inventory} + \text{Ending Inventory}}{2} \div \frac{\text{COGS}}{365}$$

$$\text{DPO (days)} = \frac{\text{Starting AP} + \text{Ending AP}}{2} \div \frac{\text{COGS}}{365}$$

"Inventory turnover is a ratio showing how many times a company has sold and replaced inventory during a given period. A company can then divide the days in the period by the inventory turnover formula to calculate the days it takes to sell the inventory on hand. Calculating inventory turnover can help businesses make better decisions on pricing,

manufacturing, marketing and purchasing new inventory", Marshall (2020). We calculated the inventory turn with the formula below.

$$\text{Inventory Turn (IT)} = \frac{COGS}{Average\ inventory}$$

We computed CCC and IT from public companies against the case company to analyse the company performance. Since the case company is one of the significant air filtration manufacturers in terms of revenue and number of employees, we assume it is appropriate to compare with the public listed company even if they might adopt different company strategies to fulfill the stakeholders' interest. We extracted the 2018 annual report data, which was downloaded from the respective public company website. USD currency was the base currency for data comparison. Non-USD currencies were converted to USD currency based on the exchange rate of the analysis date. Euro to USD at 1.101815, MYR to USD at 0.24, and SEK to USD at 0.02447001. DSO, DIO, and DPO are calculated based on the unit measurement of days.

3.3.2 GMROI Analysis

"A gross margin return on investment (GMROI) is an inventory profitability evaluation ratio that analyzes a firm's ability to turn inventory into cash above the cost of the inventory. It is calculated by dividing the gross margin by the average inventory cost and is used often in the retail industry.", Will (2019). We calculated the GMROI with the formula below.

$$\text{GMROI} = \frac{Gross\ Profit}{Average\ inventory\ cost}$$

We compute GMROI from public companies against the case company to analyse the return of investment for inventory. The same data source, currency, and currency conversion rate were used as per CCC and IT analysis to ensure consistency.

Slow-moving items (item with low IT) could have different gross profits. A slow-moving item with high gross profit is not a problem. Since the Inventory Turn formula does not take

gross profit into consideration, it does not give an accurate picture of a company's inventory performance, i.e., the ability to turn inventory into profit. GMROI, however, takes the SKU profit into consideration in its formula. This normalization allows us to compare which SKU is having better performance and a better indicator to measure the inventory performance of a company.

3.3.3 Demand and Supply Variability Analysis

In Make-to-Order (MTO) environment, our production order is considered as firm demand for our SKUs. Therefore, we would like to analyze the demand variability of our SKUs. We compute the demand variability based on the quantity ordered for each SKU in each work order and compute the coefficient of variation. For each SKUs in A1 and A2 product groups. Similarly, we investigate the supply variability, i.e., the production lead time for each order to meet the quoted service level.

We define the CV range for low volatile, moderately volatile, and highly volatile as below to standardize the analysis.

Low Volatile	$CV < 0.8$
Moderately Volatile	$0.8 \leq CV \leq 1.2$
Highly Volatile	$CV > 1.2$

The Demand and Supply variability analysis will allow us to identify and prioritize the SKUs for further analysis.

3.3.4 ABC Analysis

We performed an analysis on SKU order line frequency to determine high-demand items. We validated against the case company ABC categorization based on the order line frequency and confirmed that all A1 SKU items were highly demanded items. Since the case company is a manufacturing plant and all production orders are firmed customer demand, we use this validation result to confirm that A1 items will be our target for further analysis. We presented this result to the case company representatives and received a confirmation of our approach.

3.3.5 Cycle Service Level Analysis

We compared the actual performance of delivery lead time from production against target CSL with customers. We examine the production lead time of individual work orders and compute the percentage of work orders meeting the quoted lead time based on product groups. Similarly, the objective here is to identify which Product Group may have a Cycle Service Level issue.

Product Groups	Quoted CSL	Lead Time
A1	90%	4 days
A2	90%	6 days

3.3.6 Inventory Policy Analysis

Once we identified which product group has high volatility as well as facing CSL issues, we prioritize this product group as our target for further analysis. To perform a sample analysis, we identified an SKU family, High Flow Series air filters, and investigated the bill of material information. We narrowed it down to 14 raw materials for further inventory holding analysis.

We computed the Total Inventory Relevant Cost and average annual inventory value using two other inventory models, namely periodic review policy (R,S) and continuous review policy (s,Q) model, and comparing our results against that of the current inventory policy the identified raw materials. We check the distribution profile for the 14 individual raw materials involved using the tool called @Risk. All 14 raw materials demonstrated Normal distribution.

3.3.6.1 Current Inventory Policy

The current inventory policy in the case company is such that the inventory analyst will perform a Periodic Review (weekly) and check whether the inventory position of raw materials is below the Reorder Point. If yes, the raw material will be replenished with a reorder quantity. The formula involved are as below:

$$\text{Reorder Quantity} = \text{EOQ} = \sqrt{2 \times \text{Annual Consumption} \times \text{Ordering Cost}}$$

Safety Stock, SS = Lead time (weeks) x Consumption (per week) x relevant lead time consumption multiple

*Lead time consumption multiple = 1.0 for raw materials with lead time > 4 weeks, or 0.5 for raw materials with lead time <= 4 weeks.

Reorder Point, s = Consumption (per week) x Lead time (weeks) + Safety Stock

We observed that the formula involved in the current inventory policy does not take the target Cycle Service Level (CSL) into consideration.

3.3.6.2 Periodic Review Policy (R,S)

We explored our analysis using Period Review Policy (R,S) with the following formula involved. The Periodic Review policy basically means that during each review period R, we will check the inventory position and put in a replenishment order with order quantity as many as the Order-up-to level, S.

Target Cycle Service Level = 90%

Order-up-to Level, $S = \mu_{DL+R} + k\sigma_{DL+R}$ where Review Period, R = 1 week

Safety Stock, SS = $k\sigma_{DL+R}$

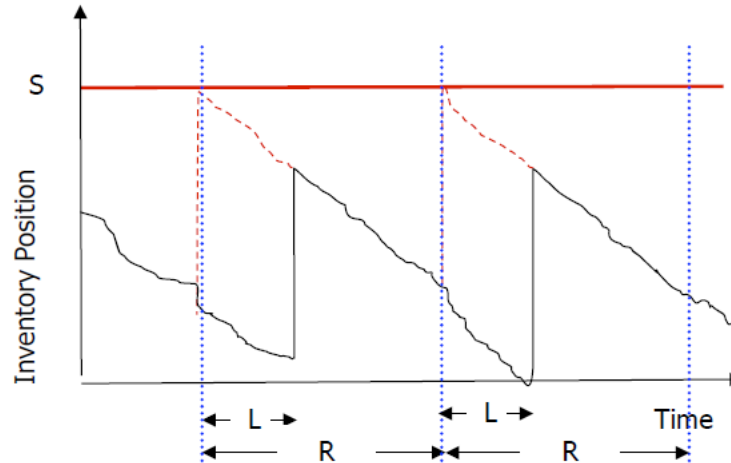


Image credit: CTL.SC1x - Supply Chain and Logistics Fundamentals, Periodic Review Inventory Policies

Figure 11: Illustration of Periodic Review Policy (R,S) Model

3.3.6.3 Continuous Review Policy (s,Q)

We also explore the Continuous Review Policy (s,Q) in our analysis. In the Continuous Review policy, we will replenish with Reorder Quantity Q (computed using EOQ formula) whenever the inventory position is below the Reorder Point, s. The formula involved are as below:

$$\text{Reorder Quantity, EOQ} = \sqrt{\frac{2 \times \text{Annual Consumption} \times \text{Ordering Cost}}{r \times C}}$$

where

r = working capital rate

C = holding cost per unit

Target CSL = 90%

Safety Stock, $SS = k\sigma_{DL}$

Reorder point, $s = \mu_{DL} + k\sigma_{DL}$

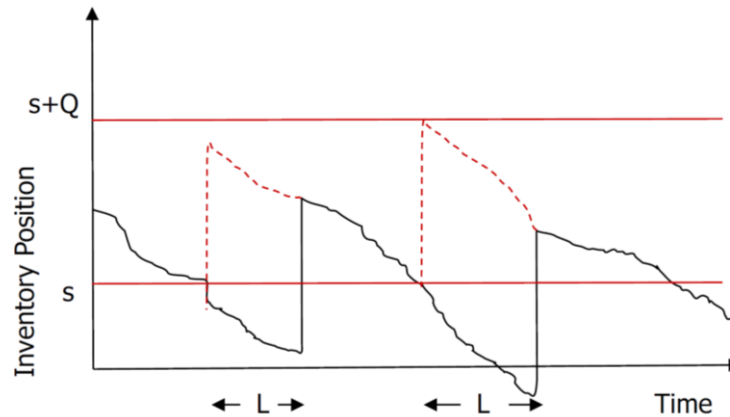


Image credit: CTL.SC1x - Supply Chain and Logistics Fundamentals, Continuous Review Inventory Policies

Figure 12: Illustration of Continuous Review Policy (s,Q) Model

3.3.7 Inventory Holding Cost Analysis

Inventory Holding Cost (IHC) is evaluated with the cost of working capital plus warehousing expenses. The Weighted Average Cost of Capital is assumed at 40% equity and 60% loan, where the rate of shareholder return is set at 10% while the loan at 12%. Based on these assumptions, the computed holding rate cost is 22%.

3.3.8 Total Inventory Relevant Cost Analysis

When we discuss inventory management costs being high, many people focus purely on the average inventory value registered in the accounting system. However, as per the literature review, optimizing the Total Inventory Relevant Cost is also important besides the average annual inventory value. Therefore, in our analysis, we calculate the Total Inventory Relevant Cost and the resulting average annual inventory value for each of the three policies. Total Inventory Relevant Cost consists of 3 cost components as per the formula below.

Total Inventory Relevant Cost (TRC) = Ordering Cost + Inventory Carrying Cost + Pipeline Inventory Carrying Cost

Average Annual Inventory Value = (Inventory Value at the beginning of the year + Inventory Value at the end of the year) / 2

3.3.9 Data Validation

The data collected was validated during a face-to-face discussion with the case company. First, we show the data source extracted from the information source provided. From there, we proceed to the steps for our initial analysis of Inventory Turn (IT), Cash Conversion Cycle (CCC), Gross Margin Return on Investment (GMROI), Demand and Supply variability analysis, and Cycle Service Level analysis. Finally, we share our initial results and validate them with the case company's Supply Chain representative. We receive positive confirmation of our results where the representative confirms SKUs indeed in the A1 product group are their main concern as they realized that they could hardly meet the target CSL. Feedback provided was taken into consideration to improve our research.

4 Results

In this section, we present our research result based on our research settings stated in the previous chapter. The case company contributed much higher CCC (113 days) compared to its competitors while the IT was 3.9 turns. Our analysis showed that the company's GMROI was going down year-on-year from 3.33 to 1.93, and this GMROI measure was one of the lowest among its competitors. It gives a shred of good evidence that the case company struggles with its inventory, i.e., high inventory value holding but low gross margin. The Demand variability and supply variability analysis results showed that A1 SKU items had higher volatility in demand variability. Hence, we prioritized and dived into the SKUs of the A1 product group, which has high volatility, and identified the High Flow series air filters for our further analysis. We validated this with the case company representative and received positive confirmation of the analysis. Subsequently, using the bill of material information, we identified 14 common raw materials for further analysis. Using the historical work order and raw material consumption data from 2016-2018, we computed analysis using three inventory policy models, the current policy, the Periodic Review Policy (R,S), and the Continuous Review Policy (s,Q). From the results, we noticed that the Periodic Review Policy could achieve a potential savings of 35% in Total Inventory Relevant Cost and a reduction of 25% in average annual inventory value across three years. The Continuous Review Policy (s,Q) could achieve a potential savings of 39% in Total Inventory Relevant Cost and a reduction of 28% in average annual inventory value across three years.

4.1 CCC and IT Result

As per Figure 13, the case company had 58 DIO days, 89 DSO days, 23 DPO days. Hence, the CCC was 113 days. This CCC figure showed that the case company required 113 days to convert its investments in inventory and other resources into cash flows from sales. The case company had 3.9 inventory turns for the year 2018.

	currency (USD)
Starting Inventory	\$ 6,736,280
Ending Inventory	\$ 8,385,573
Starting A/R	\$ 4,811,629
Ending A/R	\$ 5,989,695
Starting A/P	\$ 3,791,743
Ending A/P	\$ 261,419
COGS	\$ 29,677,182
Sales	\$ 44,242,509
DIO (days)	93
DSO (days)	45
DPO (days)	25
Cash Conversion Cycle (days)	113
NOWC Required (AR+Inv-A/P)	\$ 14,113,849
Inventory Turns	3.9

Figure 13: CCC and IT for the Case Company Year 2018

Figure 14 showed the CCC and IT results from our computation for the case company and its competitors. We noticed that Ahlstrom Munksjo Oyj had the lowest 18 days for CCC while Donaldson had the second highest in CCC of 87 days which is much lower than our case company's CCC (113 days). The highest inventory turns among the eight companies belonged to CECO, which showed 10.81 inventory turns. The lowest Inventory Turn was 3.39 times, indicating within Ahlstrom Munksjo Oyj, Lindab International AB, and Nederman Holding AB.

Company Name	01.Parker Hanriffin Corporation	02.Donaldson	03.Colfax Corporation	04.Ahlstrom Munksjo Oyj	05.Lydall Inc.	06.Lindab International AB	07.CECO Environmental Corp.	08.Nederman Holding AB	09.The Case Company
Reporting Period	30/6/2018	31/7/2018	31/12/2018	31/12/2018	31/12/2018	31/12/2018	31/12/2018	31/12/2018	31/12/2018
	Amount (USD)	Amount (USD)	Amount (USD)	Amount (USD)	Amount (USD)	Amount (USD)	Amount (USD)	Amount (USD)	currency (USD)
Starting Inventory	1,549,494,000	239,500,000	429,627,000	311,042,375	80,339,000	131,214,333	20,969,000	40,409,000	6,736,280
Ending Inventory	1,621,304,000	334,100,000	496,535,000	473,339,724	84,465,000	141,034,514	20,817,000	58,712,146	8,385,573
Starting A/R	1,931,000,000	497,700,000	970,199,000	223,448,082	116,712,000	142,392,624	67,990,000	55,316,870	4,811,629
Ending A/R	2,146,000,000	534,600,000	989,418,000	320,517,984	144,938,000	137,587,003	53,225,000	60,467,242	5,989,695
Starting A/P	1,300,496,000	194,000,000	587,129,000	409,324,273	71,931,000	90,262,089	45,409,000	31,226,086	3,791,743
Ending A/P	1,430,306,000	201,300,000	640,667,000	511,572,705	73,265,000	82,322,368	51,984,000	46,447,366	261,419
COGS	10,762,841,000	1,798,700,000	2,533,973,000	1,331,212,883	633,252,000	720,320,719	225,802,000	232,654,712	29,677,182
Sales	14,302,392,000	2,734,200,000	3,666,812,000	2,686,224,970	785,897,000	974,287,313	337,339,000	371,275,969	44,242,509
DIO (days)	54	58	67	108	47	69	34	78	93
DSO (days)	52	69	98	37	61	52	66	57	45
DPO (days)	46	40	88	126	42	44	79	61	25
Cash Conversion Cycle (days)	59	87	76	18	66	78	21	74	113
NOWC Required (AR+Inv-A/P)	2,336,515,000	667,400,000	845,286,000	282,285,003	156,138,000	196,299,149	22,058,000	72,732,022	14,113,849
Inventory Turns	6.79	6.27	5.47	3.39	7.68	5.29	10.81	4.69	3.93

Figure 14: CCC and IT Comparison with the Case Company Year 2018

4.2 GMROI Result

Figure 15 showed the GMROI for the case company from the year 2016 to 2018. In the year 2016, the GMROI was around 4.4. It showed a downward trend from the year 2016 to 2018. There was a noticeable reduction of GMROI from the year 2017 to 2018. In other words, the case company was getting lesser ROI for its inventory investment over the years since 2016.

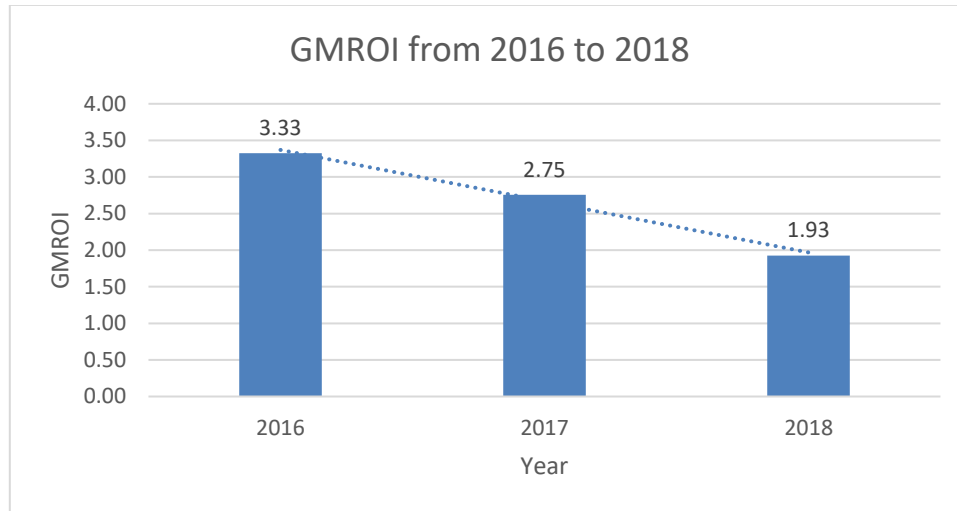


Figure 15: GMROI for the Case Company from the Year 2016 - 2018

Figure 16 showed the GMROI for public companies in the year 2018.

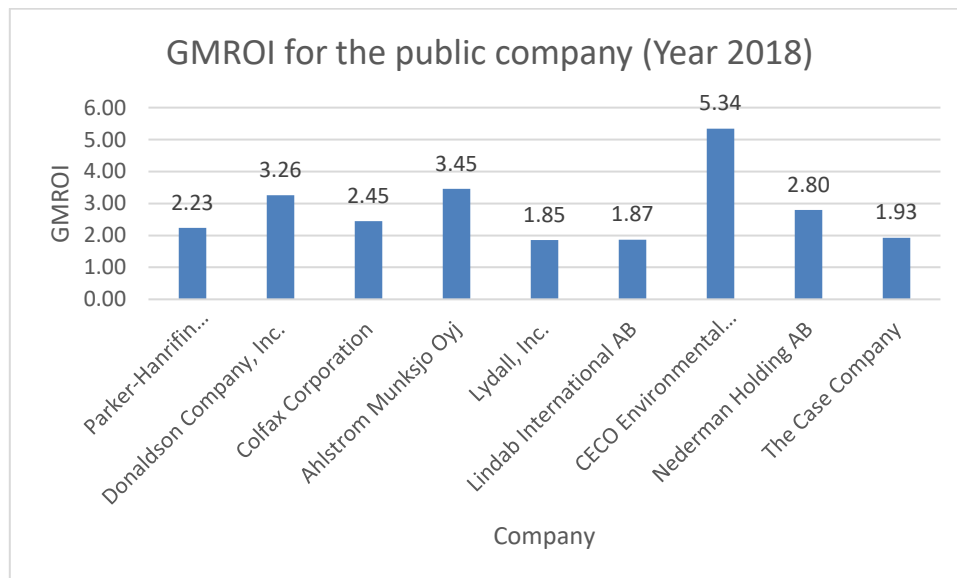


Figure 16: GMROI for the Public Companies Year 2018

Figure 17 showed the GMROI Comparison with the Case Company Year 2018. We analyzed both GMROI at product inventory level and raw material inventory level. Our analysis showed that the company's GMROI was going down year on year to 1.93. Other competitors were around 3 to 5. This result provided us an early indication that the company might have too much inventory.

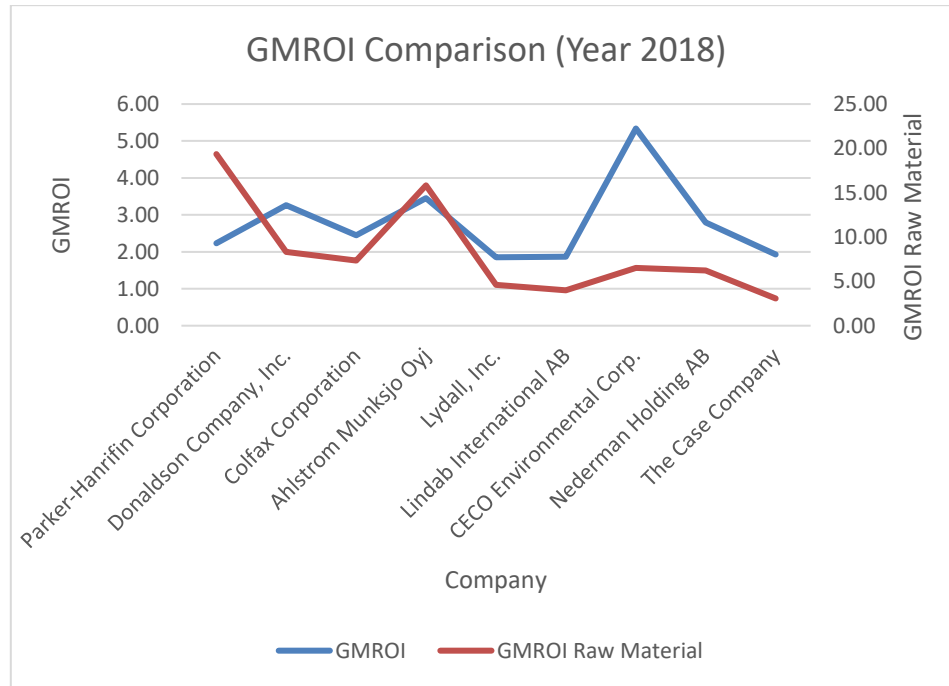


Figure 17: GMROI Comparison with the Case Company Year 2018

4.3 Demand Variability Analysis Result

Figure 18 showed the demand variability based on actual work order quantity from the year 2016 to 2018. We grouped the results into low volatile ($CV < 0.8$), moderately volatile ($0.8 \leq CV \leq 1.2$) and highly volatile ($CV > 1.2$). Our analysis showed that SKUs in product group A1 have high volatility (45% of the SKUs had $CV > 1.2$), and SKUs in product group A2 similarly have high volatility (26% of the SKUs had $CV > 1.2$). Meanwhile, SKUs in product group B have less volatility, where 87% of SKUs have $CV < 0.8$.

CV Range	Demand variability CSG A1	Demand variability CSG A2	Demand variability CSG B
CV < 0.8 (Low Volatile)	30%	47%	87%
$0.8 \leq CV \leq 1.2$ (Moderately Volatile)	25%	27%	6%
CV > 1.2 (Highly Volatile)	45%	26%	7%

Figure 18: Demand Variability Based on Work Order Quantity From 2016 - 2018

4.4 Supply Variability Analysis Result

Figure 19 showed the supply variability based on actual lead time from the year 2016 to 2018. In general, there was less volatility in Supply variability. Only 25% of SKUs in product group A1 demonstrated high volatility. SKUs in product groups A2 and B demonstrated low supply variability (6% of SKUs and 1% of SKUs had $CV > 1.2$, respectively).

CV Range	Supply variability CSG A1	Supply variability CSG A2	Supply variability CSG B
CV < 0.8 (Low Volatile)	10%	52%	90%
$0.8 \leq CV \leq 1.2$ (Moderately Volatile)	65%	42%	9%
CV > 1.2 (Highly Volatile)	25%	6%	1%

Figure 19: Supply Variability Based on Actual Lead Time From 2016 – 2018

With the analysis of Demand and Supply variability, we concluded that the case company faced significantly higher volatility in Demand (Order Quantities) than supply (work order production lead time). With high volatility in Demand in an MTO environment, raw material inventory planning becomes extremely important to ensure timely availability of raw material for production and yet maintaining low inventory holding costs.

4.5 ABC Analysis Result

Figure 20 showed the SKU Items from the A1 product group that we identified based on the SKU order line frequency analysis to determine high-demand items. A total of 20 SKUs in the A1 product group were presented to the case company to confirm the financial contribution before further analysis of the raw material was computed. From the discussion, our results were validated and confirmed. We were advised to select one of the SKU families for further analysis. We identified the High Flow Series air filters for further study. Based on the bill of material information, we narrowed it down to 14 common raw materials used.

14XXXX4	52XXX12
17XXXX1	52XXX13
17XXXX2	52XXX15
17XXXX3	54XF-FGX4988XXX5
24XXXX7	54XF-FGX4988XXX6
241XXX7	54XF-FGX4988XX12
27XXX25	54XF-FGX59413XX1
27XXX27	54XF-FG1163XXXX5
52XXXX3	54XF-FG1163XXXX6
52XXXX6	54XF-FG1163XXXX7

Figure 20: SKU Items from CSG A1

4.6 Cycle Service Level Analysis Result

Figure 21 showed the Cycle Service Level (CSL) analysis result. The case company quoted 90% Cycle Service Level. However, our analysis showed that they could not meet that. From our research, we found out the actual CSL for SKUs in the A1 product group was 61% and SKUs in the A2 product group was 75%, while quoted CSL for A1 is 90% within four days, and A2 is 90% within six days.

Product Category	Actual CSL	Quoted CSL	Lead Time
A1	61%	90%	4 days
A2	75%	90%	6 days

Figure 21: Cycle Service Level Analysis Result

4.7 Inventory Policies Analysis and Result

We computed analysis on three inventory policies, namely the Current Policy, Periodic Review Policy (R,S), and Continuous Review Policy (s,Q). Results are shown below.

4.7.1 Current Policy

Figure 22 showed the raw material unit cost, lead time (days), ordering frequency, average weekly demand, standard deviation, cycle stock, safety stock, average daily pipeline inventory for current policy from 2016 to 2018.

Current Policy						
Raw Material	Unit Cost, C	Lead Time (Days)	USD	2016	2017	2018
Raw Material 01	1.93	7	Ordering Frequency	15	17	14
			Average weekly Demand, μ	991		
			Standard Deviation, σ	-		
			Cycle Stock, $Q/2$	1550		
			Safety Stock, SS	500		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	142	142	142
Raw Material 02	4.11	30	Ordering Frequency	21	19	22
			Average weekly Demand, μ	1748		
			Standard Deviation, σ	-		
			Cycle Stock, $Q/2$	2050		
			Safety Stock, SS	3700		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	250	250	250
Raw Material 03	7.43	30	Ordering Frequency	6	6	8
			Average weekly Demand, μ	163		

			Standard Deviation, σ	-		
			Cycle Stock, Q/2	600		
			Safety Stock, SS	300		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	23	23	23
Raw Material 04	4.14	45	Ordering Frequency	34	31	36
			Average weekly Demand, μ	4763		
			Standard Deviation, σ	-		
			Cycle Stock, Q/2	3400		
			Safety Stock, SS	30600		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	680	680	680
Raw Material 05	3.73	90	Ordering Frequency	29	30	38
			Average weekly Demand, μ	4305		
			Standard Deviation, σ	-		
			Cycle Stock, Q/2	3200		
			Safety Stock, SS	55348		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	615	615	615
Raw Material 06	1.68	45	Ordering Frequency	9	8	9
			Average weekly Demand, μ	319		
			Standard Deviation, σ	-		
			Cycle Stock, Q/2	900		
			Safety Stock, SS	1000		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	46	46	46
Raw Material 07	0.98	7	Ordering Frequency	11	9	9
			Average weekly Demand, μ	391		
			Standard Deviation, σ	-		
			Cycle Stock, Q/2	1000		
			Safety Stock, SS	196		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	56	56	56

Raw Material 08	0.11	30	Ordering Frequency	52	52	52
			Average weekly Demand, μ	18521		
			Standard Deviation, σ	-		
			Cycle Stock, Q/2	6650		
			Safety Stock, SS	39700		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	2646	2646	2646
Raw Material 09	1.68	30	Ordering Frequency	13	5	1
			Average weekly Demand, μ	145		
			Standard Deviation, σ	-		
			Cycle Stock, Q/2	550		
			Safety Stock, SS	300		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	21	21	21
Raw Material 10	0.07	30	Ordering Frequency	22	18	18
			Average weekly Demand, μ	1567		
			Standard Deviation, σ	-		
			Cycle Stock, Q/2	1950		
			Safety Stock, SS	3400		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	224	224	224
Raw Material 11	0.02	7	Ordering Frequency	33	37	28
			Average weekly Demand, μ	4763		
			Standard Deviation, σ	-		
			Cycle Stock, Q/2	3500		
			Safety Stock, SS	2382		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	680	680	680
Raw Material 12	1.04	45	Ordering Frequency	36	39	41
			Average weekly Demand, μ	6442		
			Standard Deviation, σ	-		
			Cycle Stock, Q/2	4000		
			Safety Stock, SS	20708		

			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	920	920	920
Raw Material 13	0.06	7	Ordering Frequency	45	52	52
			Average weekly Demand, μ	18286		
			Standard Deviation, σ	-		
			Cycle Stock, $Q/2$	6600		
			Safety Stock, SS	9100		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	2612	2612	2612
Raw Material 14	0.16	30	Ordering Frequency	49	52	52
			Average weekly Demand, μ	12304		
			Standard Deviation, σ	-		
			Cycle Stock, $Q/2$	5400		
			Safety Stock, SS	26400		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	1758	1758	1758

Figure 22: The Case Company's Current Inventory Policy for 14 Raw Materials

4.7.2 Periodic Review Policy (R,S)

Figure 23 showed the raw material unit cost, lead time (days), ordering frequency, average weekly demand, standard deviation, cycle stock, safety stock, average daily pipeline inventory for Periodic Review Policy (R,S) with CSL = 90% from the year 2016 to 2018.

Periodic Review Policy (R,S) with CSL = 90%						
Raw Material	Unit Cost, C	Lead Time (Days)	USD	2016	2017	2018
Raw Material 01	1.93	7	Ordering Frequency	52	51	52
			Average weekly Demand, μ	915		
			Standard Deviation, σ	461		
			Cycle Stock, $Q/2$	458		
			Safety Stock, SS	836		

			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	131	131	131
Raw Material 02	4.11	30	Ordering Frequency	52	51	52
			Average weekly Demand, μ	1614		
			Standard Deviation, σ	622		
			Cycle Stock, $Q/2$	807		
			Safety Stock, SS	1833		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	231	231	231
Raw Material 03	7.43	30	Ordering Frequency	50	51	52
			Average weekly Demand, μ	151		
			Standard Deviation, σ	76		
			Cycle Stock, $Q/2$	250		
			Safety Stock, SS	223		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	22	22	22
Raw Material 04	4.14	45	Ordering Frequency	45	51	52
			Average weekly Demand, μ	4397		
			Standard Deviation, σ	1726		
			Cycle Stock, $Q/2$	2198		
			Safety Stock, SS	6029		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	628	628	628
Raw Material 05	3.73	90	Ordering Frequency	39	52	52
			Average weekly Demand, μ	4019		
			Standard Deviation, σ	1648		
			Cycle Stock, $Q/2$	1700		
			Safety Stock, SS	7861		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	574	574	574
Raw Material 06	1.68	45	Ordering Frequency	51	51	52
			Average weekly Demand, μ	295		
			Standard Deviation, σ	180		

			Cycle Stock, Q/2	700		
			Safety Stock, SS	630		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	42	42	42
Raw Material 07	0.98	7	Ordering Frequency	52	52	52
			Average weekly Demand, μ	361		
			Standard Deviation, σ	202		
			Cycle Stock, Q/2	181		
			Safety Stock, SS	366		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	52	52	52
Raw Material 08	0.11	30	Ordering Frequency	52	51	52
			Average weekly Demand, μ	17097		
			Standard Deviation, σ	8180		
			Cycle Stock, Q/2	8548		
			Safety Stock, SS	24101		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	2442	2442	2442
Raw Material 09	1.68	30	Ordering Frequency	52	41	14
			Average weekly Demand, μ	272		
			Standard Deviation, σ	162		
			Cycle Stock, Q/2	136		
			Safety Stock, SS	476		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	39	39	39
Raw Material 10	0.07	30	Ordering Frequency	52	51	52
			Average weekly Demand, μ	1447		
			Standard Deviation, σ	657		
			Cycle Stock, Q/2	723		
			Safety Stock, SS	1937		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	207	207	207
	0.02	7	Ordering Frequency	52	52	52

Raw Material 11			Average weekly Demand, μ	4402		
			Standard Deviation, σ	2392		
			Cycle Stock, $Q/2$	2201		
			Safety Stock, SS	4336		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	629	629	629
Raw Material 12	1.04	45	Ordering Frequency	52	51	51
			Average weekly Demand, μ	5947		
			Standard Deviation, σ	3508		
			Cycle Stock, $Q/2$	2973		
			Safety Stock, SS	12252		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	850	850	850
Raw Material 13	0.06	7	Ordering Frequency	48	51	52
			Average weekly Demand, μ	16879		
			Standard Deviation, σ	7012		
			Cycle Stock, $Q/2$	8440		
			Safety Stock, SS	12709		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	2411	2411	2411
Raw Material 14	0.16	30	Ordering Frequency	52	51	52
			Average weekly Demand, μ	11358		
			Standard Deviation, σ	7264		
			Cycle Stock, $Q/2$	5679		
			Safety Stock, SS	21402		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	1623	1623	1623

Figure 23: Periodic Review Policy (R,S) for 14 Raw Materials – 90% CSL

4.7.3 Continuous Review Policy (s,Q)

Figure 24 showed the raw material unit cost, lead time (days), ordering frequency, average weekly demand, standard deviation, cycle stock, safety stock, average daily pipeline inventory for Continuous Review Policy (s,Q) with CSL = 90% from the year 2016 to 2018.

Continuous Review Policy (s,Q) with CSL = 90%						
Raw Material	Unit Cost, C	Lead Time (Days)	USD	2016	2017	2018
Raw Material 01	1.93	7	Ordering Frequency	21	24	20
			Average weekly Demand, μ	915		
			Standard Deviation, σ	461		
			Cycle Stock, Q/2	1100		
			Safety Stock, SS	591		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	131	131	131
Raw Material 02	4.11	30	Ordering Frequency	40	39	46
			Average weekly Demand, μ	1614		
			Standard Deviation, σ	622		
			Cycle Stock, Q/2	1000		
			Safety Stock, SS	1650		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	231	231	231
Raw Material 03	7.43	30	Ordering Frequency	12	16	19
			Average weekly Demand, μ	151		
			Standard Deviation, σ	76		
			Cycle Stock, Q/2	250		
			Safety Stock, SS	201		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year	22	22	22
Raw Material 04	4.14	45	Ordering Frequency	61	64	75
			Average weekly Demand, μ	4397		
			Standard Deviation, σ	1726		
			Cycle Stock, Q/2	1650		
			Safety Stock, SS	5608		

			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	628	628	628
Raw Material 05	3.73	90	Ordering Frequency	39	57	72
			Average weekly Demand, μ	4019		
			Standard Deviation, σ	1648		
			Cycle Stock, $Q/2$	1700		
			Safety Stock, SS	7572		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	574	574	574
Raw Material 06	1.68	45	Ordering Frequency	11	11	11
			Average weekly Demand, μ	295		
			Standard Deviation, σ	180		
			Cycle Stock, $Q/2$	700		
			Safety Stock, SS	586		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	42	42	42
Raw Material 07	0.98	7	Ordering Frequency	11	9	9
			Average weekly Demand, μ	361		
			Standard Deviation, σ	202		
			Cycle Stock, $Q/2$	1000		
			Safety Stock, SS	259		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	52	52	52
Raw Material 08	0.11	30	Ordering Frequency	19	22	24
			Average weekly Demand, μ	17097		
			Standard Deviation, σ	8180		
			Cycle Stock, $Q/2$	20600		
			Safety Stock, SS	21702		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	2442	2442	2442
Raw Material 09	1.68	30	Ordering Frequency	11	5	0
			Average weekly Demand, μ	272		
			Standard Deviation, σ	162		

			Cycle Stock, Q/2	650		
			Safety Stock, SS	429		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	39	39	39
Raw Material 10	0.07	30	Ordering Frequency	6	5	4
			Average weekly Demand, μ	1447		
			Standard Deviation, σ	657		
			Cycle Stock, Q/2	7600		
			Safety Stock, SS	1744		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	207	207	207
Raw Material 11	0.02	7	Ordering Frequency	6	5	0
			Average weekly Demand, μ	4402		
			Standard Deviation, σ	2392		
			Cycle Stock, Q/2	22050		
			Safety Stock, SS	3066		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	629	629	629
Raw Material 12	1.04	45	Ordering Frequency	36	41	42
			Average weekly Demand, μ	5947		
			Standard Deviation, σ	3508		
			Cycle Stock, Q/2	3850		
			Safety Stock, SS	11398		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	850	850	850
Raw Material 13	0.06	7	Ordering Frequency	15	16	17
			Average weekly Demand, μ	16879		
			Standard Deviation, σ	7012		
			Cycle Stock, Q/2	26600		
			Safety Stock, SS	8986		
			Average Daily Pipeline Inventory, Pipe = <i>Total Item Days in the Pipeline per year/Days per year</i>	2411	2411	2411
	0.16	30	Ordering Frequency	26	22	17

Raw Material 14			Average weekly Demand, μ		11358		
			Standard Deviation, σ		7264		
			Cycle Stock, $Q/2$		13650		
			Safety Stock, SS		19272		
			Average Daily Pipeline Inventory, Pipe = Total Item Days in the Pipeline per year/Days per year		1623	1623	1623

Figure 24: Continuous Review Policy (s,Q) for 14 Raw Materials – 90% CSL

4.8 Total Inventory Relevant Cost Analysis Result

The Total Inventory Relevant Cost was calculated by summing up the Ordering Cost, the Inventory Carrying Cost, and the Pipeline Inventory Carrying Cost. Figures 25, 26, and 27 showed the Total Inventory Relevant Cost of Current Policy, Periodic Review Policy with CSL = 90%, and Continuous Review Policy with CSL = 90%.

Current Policy							
Raw Material	Unit Cost, C	Lead Time (Days)	USD	2016	2017	2018	Total
Raw Material 01	1.93	7	Ordering Cost, OC $= n * Ct$	360	408	336	1,104
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	872	872	872	2,617
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	422	422	422	1,265
			Total Inventory Relevant Cost $= OC + ICC + PICC$	1,654	1,702	1,630	4,985
			Average Inventory Value	5,141	5,919	5,568	5,543
Raw Material 02	4.11	30	Ordering Cost, OC $= n * Ct$	504	456	528	1,488
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	5,193	5,193	5,193	15,580
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	6,766	6,766	6,766	20,299
			Total Inventory Relevant Cost $= OC + ICC + PICC$	12,464	12,416	12,488	37,367
			Average Inventory Value	54,829	60,835	59,762	58,475

Raw Material 03	7.43	30	Ordering Cost, OC $= n * Ct$	144	144	192	480
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	1,471	1,471	1,471	4,414
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	1,142	1,142	1,142	3,426
			Total Inventory Relevant Cost $= OC + ICC + PICC$	2,758	2,758	2,806	8,321
			Average Inventory Value	12,318	13,188	12,100	12,535
Raw Material 04	4.14	45	Ordering Cost, OC $= n * Ct$	816	744	864	2,424
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	30,985	30,985	30,985	92,955
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	27,904	27,904	27,904	83,713
			Total Inventory Relevant Cost $= OC + ICC + PICC$	59,705	59,633	59,753	179,092
			Average Inventory Value	265,257	270,632	265,310	267,066
Raw Material 05	3.73	90	Ordering Cost, OC $= n * Ct$	696	720	912	2,328
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	48,049	48,049	48,049	144,146
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	45,424	45,424	45,424	136,272
			Total Inventory Relevant Cost $= OC + ICC + PICC$	94,169	94,193	94,385	282,746
			Average Inventory Value	421,586	423,575	418,486	421,216
Raw Material 06	1.68	45	Ordering Cost, OC $= n * Ct$	216	192	216	624
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	703	703	703	2,109
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	759	759	759	2,277
			Total Inventory Relevant Cost $= OC + ICC + PICC$	1,678	1,654	1,678	5,010
			Average Inventory Value	5,952	5,936	6,173	6,021
Raw Material 07	0.98	7	Ordering Cost, OC $= n * Ct$	264	216	216	696
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	258	258	258	775
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	84	84	84	253
			Total Inventory Relevant Cost $= OC + ICC + PICC$	607	559	559	1,725
			Average Inventory Value	1,527	1,566	1,556	1,550
	0.11	30	Ordering Cost, OC $= n * Ct$	1,248	1,248	1,248	3,744

Raw Material 08			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	1,077	1,077	1,077	3,230
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	1,844	1,844	1,844	5,532
			Total Inventory Relevant Cost $= OC + ICC + PICC$	4,169	4,169	4,169	12,507
			Average Inventory Value	7,150	-	-	2,383
Raw Material 09	1.68	30	Ordering Cost, OC $= n * Ct$	312	120	24	456
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	315	315	315	944
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	230	230	230	690
			Total Inventory Relevant Cost $= OC + ICC + PICC$	857	665	569	2,090
			Average Inventory Value	3,165	2,814	2,647	2,875
Raw Material 10	0.07	30	Ordering Cost, OC $= n * Ct$	528	432	432	1,392
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	78	78	78	233
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	98	98	98	293
			Total Inventory Relevant Cost $= OC + ICC + PICC$	703	607	607	1,918
			Average Inventory Value	738	736	709	728
Raw Material 11	0.02	7	Ordering Cost, OC $= n * Ct$	792	888	672	2,352
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	31	31	31	92
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	25	25	25	75
			Total Inventory Relevant Cost $= OC + ICC + PICC$	848	944	728	2,519
			Average Inventory Value	66	126	265	152
Raw Material 12	1.04	45	Ordering Cost, OC $= n * Ct$	864	936	984	2,784
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	5,637	5,637	5,637	16,911
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	9,448	9,448	9,448	28,345
			Total Inventory Relevant Cost $= OC + ICC + PICC$	15,949	16,021	16,069	48,040
			Average Inventory Value	67,995	67,658	65,350	67,001
Raw Material 13	0.06	7	Ordering Cost, OC $= n * Ct$	1,080	1,248	1,248	3,576
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	216	216	216	647

			Pipeline Inventory Carrying Cost, P ICC $= r * C * Pipe * L$	251	251	251	753
			Total Inventory Relevant Cost $= OC + ICC + P ICC$	1,547	1,715	1,715	4,976
			Average Inventory Value	-	-	-	-
Raw Material 14	0.16	30	Ordering Cost, OC $= n * Ct$	1,176	1,248	1,248	3,672
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	1,120	1,120	1,120	3,360
			Pipeline Inventory Carrying Cost, P ICC $= r * C * Pipe * L$	1,857	1,857	1,857	5,571
			Total Inventory Relevant Cost $= OC + ICC + P ICC$	4,153	4,225	4,225	12,603
			Average Inventory Value	-	-	-	-
Total 14 Raw Materials			Ordering Cost, OC $= n * Ct$	9,000	9,000	9,120	27,120
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	96,005	96,005	96,005	288,014
			Pipeline Inventory Carrying Cost, P ICC $= r * C * Pipe * L$	96,255	96,255	96,255	288,764
			Total Inventory Relevant Cost $= OC + ICC + P ICC$	201,259	201,259	201,379	603,898
			Average Inventory Value	845,725	852,986	837,927	845,546

Figure 25: Total Inventory Relevant Cost of Current Policy

Periodic Review Policy (R,S) with CSL = 90%								
Raw Material	Unit Cost, C	Lead Time (Days)	USD	2016	2017	2018	Total	% Diff
Raw Material 01	1.93	7	Ordering Cost, OC $= n * Ct$	1,248	1,224	1,248	3,720	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	551	551	551	1,652	
			Pipeline Inventory Carrying Cost, P ICC $= r * C * Pipe * L$	389	389	389	1,168	
			Total Inventory Relevant Cost $= OC + ICC + P ICC$	2,188	2,164	2,188	6,540	-31%
			Average Inventory Value	5,238	5,513	5,513	5,421	2%
Raw Material 02	4.11	30	Ordering Cost, OC $= n * Ct$	1,248	1,224	1,248	3,720	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	2,384	2,384	2,384	7,153	
			Pipeline Inventory Carrying Cost, P ICC $= r * C * Pipe * L$	6,248	6,248	6,248	18,743	
			Total Inventory Relevant Cost $= OC + ICC + P ICC$	9,880	9,856	9,880	29,616	21%
			Average Inventory Value	45,673	42,697	42,697	43,689	25%

Raw Material 03	7.43	30	Ordering Cost, OC $= n * Ct$	1,200	1,224	1,248	3,672	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	773	773	773	2,320	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	1,058	1,058	1,058	3,174	
			Total Inventory Relevant Cost = OC + ICC + PICC	3,031	3,055	3,079	9,166	-10%
			Average Inventory Value	8,360	7,431	7,431	7,741	38%
Raw Material 04	4.14	45	Ordering Cost, OC $= n * Ct$	1,080	1,224	1,248	3,552	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	7,497	7,497	7,497	22,492	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	25,760	25,760	25,760	77,280	
			Total Inventory Relevant Cost = OC + ICC + PICC	34,337	34,481	34,505	103,324	42%
			Average Inventory Value	209,191	160,311	173,425	180,976	32%
Raw Material 05	3.73	90	Ordering Cost, OC $= n * Ct$	936	1,248	1,248	3,432	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	7,846	7,846	7,846	23,539	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	42,406	42,406	42,406	127,219	
			Total Inventory Relevant Cost = OC + ICC + PICC	51,189	51,501	51,501	154,190	45%
			Average Inventory Value	325,932	237,052	237,052	266,678	37%
Raw Material 06	1.68	45	Ordering Cost, OC $= n * Ct$	1,224	1,224	1,248	3,696	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	492	492	492	1,477	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	702	702	702	2,105	
			Total Inventory Relevant Cost = OC + ICC + PICC	2,418	2,418	2,442	7,278	-45%
			Average Inventory Value	5,104	4,741	4,741	4,862	19%
Raw Material 07	0.98	7	Ordering Cost, OC $= n * Ct$	1,248	1,248	1,248	3,744	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	118	118	118	355	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	78	78	78	234	
			Total Inventory Relevant Cost = OC + ICC + PICC	1,444	1,444	1,444	4,333	-151%
			Average Inventory Value	779	966	1,081	942	39%
	0.11	30	Ordering Cost, OC $= n * Ct$	1,248	1,224	1,248	3,720	

Raw Material 08			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	759	759	759	2,276	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	1,702	1,702	1,702	5,107	
			Total Inventory Relevant Cost = OC + ICC + PICC	3,709	3,685	3,709	11,102	11%
			Average Inventory Value	12,392	12,091	12,091	12,192	-412%
Raw Material 09	1.68	30	Ordering Cost, OC $= n * Ct$	1,248	984	336	2,568	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	226	226	226	679	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	431	431	431	1,294	
			Total Inventory Relevant Cost = OC + ICC + PICC	1,906	1,642	994	4,542	-117%
			Average Inventory Value	3,112	3,196	3,196	3,168	-10%
Raw Material 10	0.07	30	Ordering Cost, OC $= n * Ct$	1,248	1,224	1,248	3,720	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	39	39	39	116	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	90	90	90	270	
			Total Inventory Relevant Cost = OC + ICC + PICC	1,377	1,353	1,377	4,106	-114%
			Average Inventory Value	664	634	634	644	12%
Raw Material 11	0.02	7	Ordering Cost, OC $= n * Ct$	1,248	1,248	1,248	3,744	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	34	34	34	103	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	23	23	23	69	
			Total Inventory Relevant Cost = OC + ICC + PICC	1,305	1,305	1,305	3,916	-55%
			Average Inventory Value	258	311	311	293	-93%
Raw Material 12	1.04	45	Ordering Cost, OC $= n * Ct$	1,248	1,224	1,224	3,696	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	3,474	3,474	3,474	10,421	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	8,722	8,722	8,722	26,167	
			Total Inventory Relevant Cost = OC + ICC + PICC	13,444	13,420	13,420	40,284	16%
			Average Inventory Value	62,015	58,489	58,489	59,664	11%
Raw Material 13	0.06	7	Ordering Cost, OC $= n * Ct$	1,152	1,224	1,248	3,624	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	290	290	290	871	

			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	232	232	232	695	
			Total Inventory Relevant Cost = OC + ICC + PICC	1,674	1,746	1,770	5,190	-4%
			Average Inventory Value	5,170	2,902	2,902	3,658	-
Raw Material 14	0.16	30	Ordering Cost, OC $= n * Ct$	1,248	1,224	1,248	3,720	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	954	954	954	2,861	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	1,714	1,714	1,714	5,143	
			Total Inventory Relevant Cost = OC + ICC + PICC	3,916	3,892	3,916	11,724	7%
			Average Inventory Value	12,926	13,031	13,031	12,996	-
Total 14 Raw Materials			Ordering Cost, OC $= n * Ct$	16,824	16,968	16,536	50,328	-86%
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	25,438	25,438	25,438	76,314	74%
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	89,556	89,556	89,556	268,668	7%
			Total Inventory Relevant Cost = OC + ICC + PICC	131,818	131,962	131,530	395,310	35%
			Average Inventory Value	696,814	549,364	562,592	602,923	29%

Figure 26: Total Inventory Relevant Cost of (R,S) Inventory Policy - CSL 90%

Continuous Review Policy (s,Q) with CSL = 90%								
Raw Material	Unit Cost, C	Lead Time (Days)	USD	2016	2017	2018	Total	% Diff
Raw Material 01	1.93	7	Ordering Cost, OC $= n * Ct$	504	576	480	1,560	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	719	719	719	2,158	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	389	389	389	1,168	
			Total Inventory Relevant Cost = OC + ICC + PICC	1,613	1,685	1,589	4,886	2%
			Average Inventory Value	4,835	5,409	5,772	5,339	4%
Raw Material 02	4.11	30	Ordering Cost, OC $= n * Ct$	960	936	1,104	3,000	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	2,393	2,393	2,393	7,180	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	6,248	6,248	6,248	18,743	

			Total Inventory Relevant Cost = OC + ICC + PICC	9,601	9,577	9,745	28,923	23%
			Average Inventory Value	42,307	35,997	38,824	39,043	33%
Raw Material 03	7.43	30	Ordering Cost, OC $= n * Ct$	288	384	456	1,128	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	737	737	737	2,212	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	1,058	1,058	1,058	3,174	
			Total Inventory Relevant Cost = OC + ICC + PICC	2,083	2,179	2,251	6,514	22%
			Average Inventory Value	7,859	7,243	8,755	7,953	37%
Raw Material 04	4.14	45	Ordering Cost, OC $= n * Ct$	1,464	1,536	1,800	4,800	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	6,614	6,614	6,614	19,843	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	25,760	25,760	25,760	77,280	
			Total Inventory Relevant Cost = OC + ICC + PICC	33,838	33,910	34,174	101,923	43%
			Average Inventory Value	203,328	147,603	155,537	168,823	37%
Raw Material 05	3.73	90	Ordering Cost, OC $= n * Ct$	936	1,368	1,728	4,032	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	7,609	7,609	7,609	22,828	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	42,406	42,406	42,406	127,219	
			Total Inventory Relevant Cost = OC + ICC + PICC	50,952	51,384	51,744	154,079	46%
			Average Inventory Value	322,733	229,225	230,478	260,812	38%
Raw Material 06	1.68	45	Ordering Cost, OC $= n * Ct$	264	264	264	792	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	476	476	476	1,428	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	702	702	702	2,105	
			Total Inventory Relevant Cost = OC + ICC + PICC	1,442	1,442	1,442	4,325	14%
			Average Inventory Value	5,280	5,432	5,836	5,516	8%
Raw Material 07	0.98	7	Ordering Cost, OC $= n * Ct$	264	216	216	696	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	272	272	272	816	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	78	78	78	234	
			Total Inventory Relevant Cost = OC + ICC + PICC	614	566	566	1,746	-1%

			Average Inventory Value	1,527	1,566	1,556	1,550	0%
Raw Material 08	0.11	30	Ordering Cost, OC $= n * Ct$	456	528	576	1,560	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	983	983	983	2,948	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	1,702	1,702	1,702	5,107	
			Total Inventory Relevant Cost = OC + ICC + PICC	3,141	3,213	3,261	9,615	23%
			Average Inventory Value	11,966	11,383	12,687	12,012	-404%
Raw Material 09	1.68	30	Ordering Cost, OC $= n * Ct$	264	120	-	384	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	399	399	399	1,198	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	431	431	431	1,294	
			Total Inventory Relevant Cost = OC + ICC + PICC	1,095	951	831	2,876	-38%
			Average Inventory Value	3,165	3,655	3,404	3,408	-19%
Raw Material 10	0.07	30	Ordering Cost, OC $= n * Ct$	144	120	96	360	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	136	136	136	407	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	90	90	90	270	
			Total Inventory Relevant Cost = OC + ICC + PICC	370	346	322	1,037	46%
			Average Inventory Value	916	1,284	1,138	1,113	-53%
Raw Material 11	0.02	7	Ordering Cost, OC $= n * Ct$	144	120	-	264	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	131	131	131	394	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	23	23	23	69	
			Total Inventory Relevant Cost = OC + ICC + PICC	298	274	154	727	71%
			Average Inventory Value	465	467	440	457	-200%
Raw Material 12	1.04	45	Ordering Cost, OC $= n * Ct$	864	984	1,008	2,856	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	3,479	3,479	3,479	10,436	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	8,722	8,722	8,722	26,167	
			Total Inventory Relevant Cost = OC + ICC + PICC	13,065	13,185	13,209	39,459	18%
			Average Inventory Value	62,395	58,377	55,602	58,791	12%

Raw Material 13	0.06	7	Ordering Cost, OC $= n * Ct$	360	384	408	1,152	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	489	489	489	1,466	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	232	232	232	695	
			Total Inventory Relevant Cost = OC + ICC + PICC	1,080	1,104	1,128	3,313	33%
			Average Inventory Value	5,160	2,505	2,301	3,322	-
Raw Material 14	0.16	30	Ordering Cost, OC $= n * Ct$	624	528	408	1,560	
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	1,159	1,159	1,159	3,478	
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	1,714	1,714	1,714	5,143	
			Total Inventory Relevant Cost = OC + ICC + PICC	3,498	3,402	3,282	10,181	19%
			Average Inventory Value	13,891	13,637	12,786	13,438	-
Total 14 Raw Materials			Ordering Cost, OC $= n * Ct$	7,536	8,064	8,544	24,144	11%
			Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	25,598	25,598	25,598	76,793	73%
			Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	89,556	89,556	89,556	268,668	7%
			Total Inventory Relevant Cost = OC + ICC + PICC	122,690	123,218	123,698	369,606	39%
			Average Inventory Value	685,826	523,782	535,117	581,575	31%

Figure 27: Total Inventory Relevant Cost of (s,Q) Inventory Policy - CSL 90%

Figure 28 showed the Total Inventory Relevant Cost comparison of current inventory policy against Periodic Review Policy (R,S) with CSL = 90% and Continuous Review Policy (s,Q) with CSL = 90%. Our analysis showed that using Periodic Review Policy (R,S) - the savings in Total Inventory Relevant Cost is 35% across three years and reductions in average inventory value are 25% while using Continuous Review Policy (s,Q) – the savings in Total Inventory Relevant Cost is 39%, and reduction in average inventory value is 28%

Another observation we had is that the safety stock quantity computed using the existing formula in the current policy is very high compared to the other policies. It is especially true for raw materials with a long lead time and high demand. So it was one of the reasons why we could achieve double-digit savings.

Current Policy					
Total 14 Raw Materials	USD	2016	2017	2018	Total
	Ordering Cost, OC $= n * Ct$	9,000	9,000	9,120	27,120
	Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	96,005	96,005	96,005	288,014
	Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	96,255	96,255	96,255	288,764
	Total Inventory Relevant Cost = OC + ICC + PICC	201,259	201,259	201,379	603,898
	Average Inventory Value	845,725	852,986	837,927	845,546

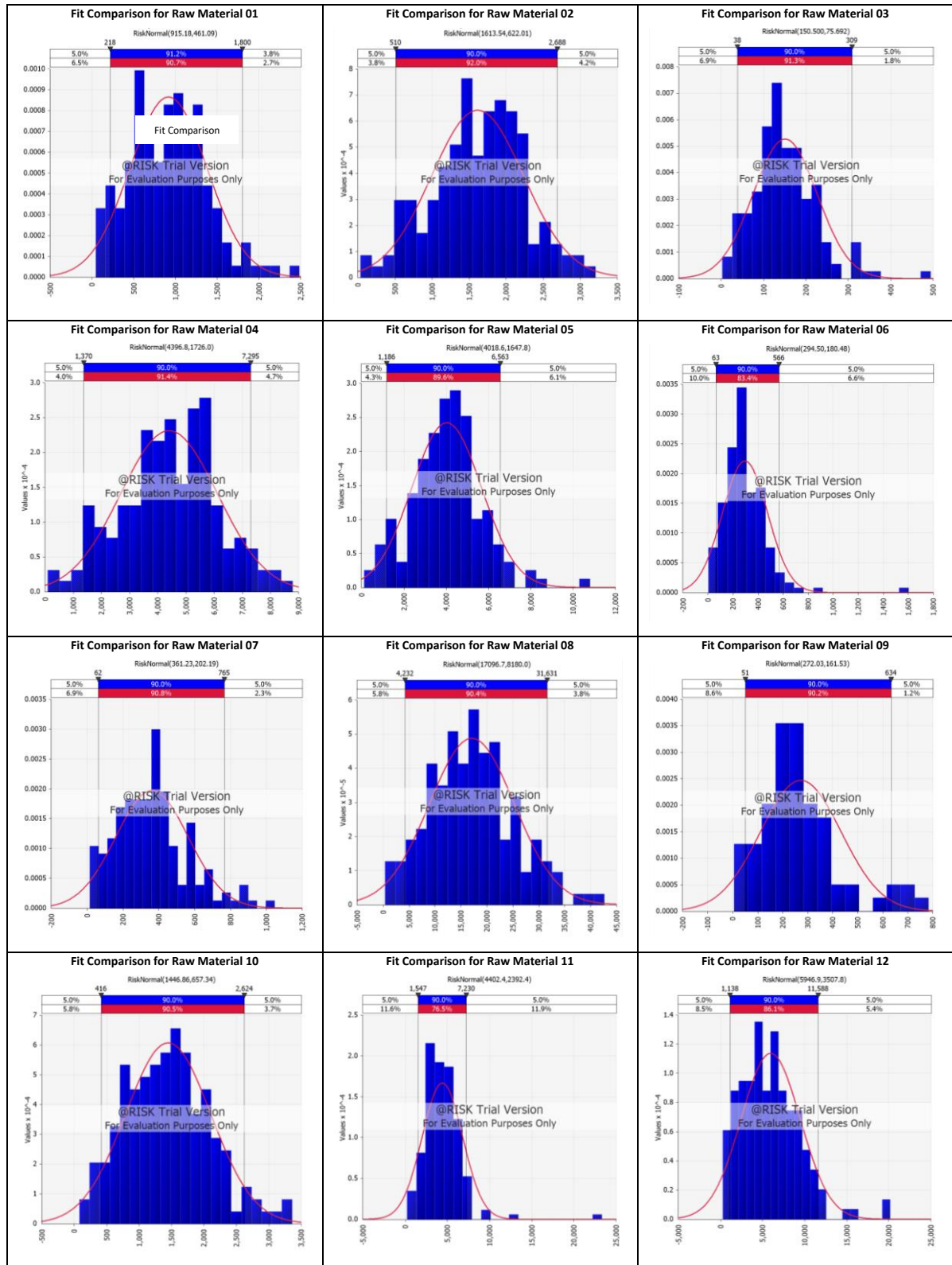
Periodic Review Policy (R,S) with CSL = 90%						
Total 14 Raw Materials	USD	2016	2017	2018	Total	% Diff
	Ordering Cost, OC $= n * Ct$	16,824	16,968	16,536	50,328	-86%
	Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	25,438	25,438	25,438	76,314	74%
	Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	89,556	89,556	89,556	268,668	7%
	Total Inventory Relevant Cost = OC + ICC + PICC	131,818	131,962	131,530	395,310	35%
	Average Inventory Value	696,814	549,364	562,592	602,923	29%

Continuous Review Policy (s,Q) with CSL = 90%						
Total 14 Raw Materials	USD	2016	2017	2018	Total	% Diff
	Ordering Cost, OC $= n * Ct$	7,536	8,064	8,544	24,144	11%
	Inventory Carrying Cost, ICC $= r * C * (Q/2 + SS)$	25,598	25,598	25,598	76,793	73%
	Pipeline Inventory Carrying Cost, PICC $= r * C * Pipe * L$	89,556	89,556	89,556	268,668	7%
	Total Inventory Relevant Cost = OC + ICC + PICC	122,690	123,218	123,698	369,606	39%
	Average Inventory Value	685,826	523,782	535,117	581,575	31%

Figure 28: Total Inventory Relevant Cost Comparison

4.9 Data Validation With @Risk

We fitted distribution to our data with a chi-square test. The test result shows most of the data are normally distributed. However, some sample data had a noise which we decided to standardize the distribution to normally distributed to ease our comparison across the research.



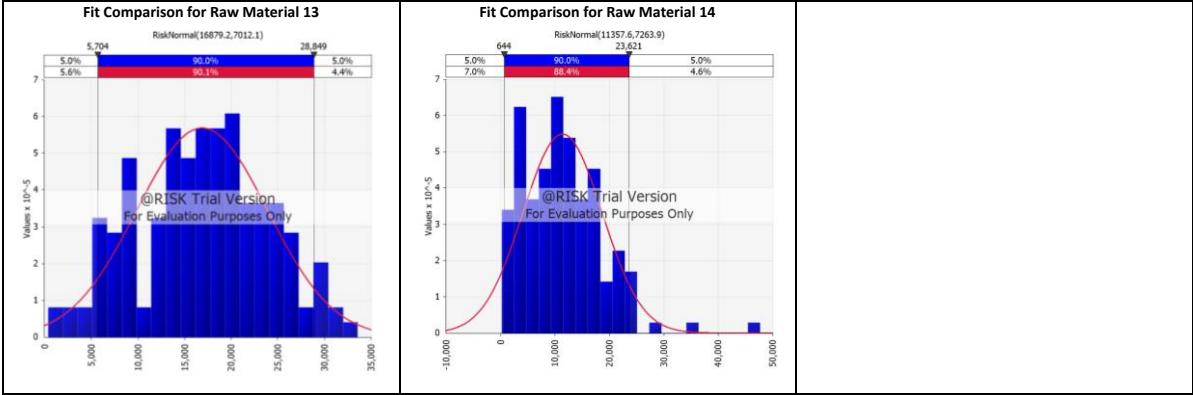


Figure 29: Fit Distribution to Data Result for 14 Raw Materials

5 Discussion

This chapter will conclude the research, recommendations to the case company and raise a few areas where future research can be focused. The research result shows many practical insights and gaps that we can observe in the case company's current inventory management practices. From the existing literature review, we adopted and applied some important concepts such as GMROI, Demand and Supply Variability analysis, and Total Inventory Relevant Cost analysis in our project, and it worked well. Finally, there are a number of recommendations that we will suggest to the company and policymakers for the MTO production environment.

5.1 Practical implications

In this research, based on the literature reviews, we have adopted many good practices which has significant value to be applied in day-to-day inventory management.

5.1.1 Make-To-Stock to Make-to-Order environment

The production process (MTS or MTO) depends on the availability of the demand information. If the demand is unknown and based on forecasted information, then we will go for MTS. On the other hand, if the demand is known at the time of production, we go for MTO. MTO/MTS thus has a significant implication to the inventory model.

5.1.2 Perform postponement and keep low finished goods inventory

If the demand information is known, it is not advisable to keep inventory as finished goods as it will incur higher holding costs. It is better to keep inventory in raw form, raw material, or sub-components. It is a form of postponement strategy and only starts the production when demand is known.

5.1.3 GMROI

Low Inventory Turn does not mean bad inventory performances. GMROI is a better indicator to evaluate inventory performance as it normalizes the profit margin.

5.1.4 Total Inventory Relevant Cost comparison

When we analyze inventory issues, it is crucial to compare the Total Inventory Relevant Cost, which comprises Ordering Cost, Inventory Holding Cost, and Pipeline Inventory Holding Cost, besides average inventory value. The inventory policy adopted for a particular raw material has to result in the lowest Total Inventory Relevant Cost.

5.2 Recommendation to the company

Our recommendation to the case company is to perform a thorough analysis of all raw materials for A1 and A2 product groups using the Periodic Review Policy. Then, assess the Total Inventory Relevant Cost. When there is a potential saving found for any items, switch to Periodic Review Policy (R,S) for those items.

Although Continuous Review policy (s,Q) could result in higher savings, this solution is more difficult to implement immediately. It requires much higher investment in digital technology to ensure integrated and real-time information flow. Besides, it would also require more stringent coordination and integration across departments.

We would like to point out that one of the reasons for the mismatch (high raw material inventory growth vs. slow sales growth) could be due to the high safety stock calculation based on the current inventory policy and formula used. The safety stock quantity calculated using the current inventory policy was much higher than the other two policies.

Furthermore, we suggest looking into the BOM analyzer's information flow and data entry to ensure the most up-to-date and accurate BOM structure is recorded. We noticed some outdated BOM information from the data provided.

We also noticed that some of the inventory quantity information was not recorded accurately. It could be due to the wrong unit of measure used in stocking the raw materials. For example, the aluminum frame. Instead of keeping the stock as each, it was kept as one box. So, upon goods issue, a box was issued out; however, only a portion of the frames was

used. The left-over raw materials were not returned and not recorded back into the system. It will result in unnecessary replenishment.

5.3 Limitations

The data extracted from public companies might include non-core business, different scale of economies, capital fund size, different production strategies, and stakeholder interest as compared with the case company. However, we assume the activities are similar within the air filtration manufacturing industry.

In our inventory analysis, we assumed there are no MOQ constraints for the 14 raw materials analyzed as we were not provided with such data. If there were MOQ constraints or other constraints such as discounts, our analysis and results could be different.

Capital structure is not provided, and we assumed at 40:60 ratio where 40% from equity and 60% from the loan. The dividend rate to the shareholders is set at 10%, while the loan is set at 12% per annual. This assumption was used to compute the working capital holding cost rate.

5.4 Avenues for future research

Reflecting on the maturity of the research topic, the research in this report defines the overall problem and offers some solutions. Nevertheless, further research is needed to develop a better model to investigate the effect of MOQ constraints, discounts, and raw materials proliferation due to finish product SKU variants. Besides that, future research can also investigate the work centers' processing time variability, which could also be a potential factor contributing to missing target CSL.

5.5 Conclusion

In a nutshell, we would like to answer our research questions. What caused the mismatch? The mismatch could be caused by high volatility in the demand variability and the safety stock calculation formula in current policy, resulting in higher safety stock. Our

recommendation is to perform Periodic Review Policy (R,S) for group A1 and A2 raw materials, assess the potential savings, and switch to the lowest cost policy.

As for key learnings, high inventory holding or low Inventory Turn does not necessarily mean we have an inventory issue. To evaluate inventory performance, GMROI gives a more accurate evaluation.

The key difference in MTS vs. MTO is the availability of demand information at the point of production, thus impacting the inventory holding; instead of carrying finish goods in MTS, we shifted upstream to carry raw materials inventory in the MTO environment.

To evaluate the different inventory policies, we have to compute and optimize Total Inventory Relevant Cost. Therefore, we aimed to strike an optimal position by balancing the Ordering Cost versus the Inventory Carrying Cost of inventory on hand and pipeline inventory.

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