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Demand-Driven Material Requirements Planning review

A case study of durable products and uneven demand in Toto Vietnam

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DECLARATION OF ORIGINALITY

I, Thi Kim Oanh Nguyen, hereby declare that this dissertation and the work reported herein was composed by originated entirely from me. Information derived from the published and unpublished work of others has been acknowledged in the text and references are given in the list of sources. This presented here has not been previously presented at this or any other university for similar purposes.

Date of submission: 27/09/2022

Signature of declarer:

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ABSTRACT

In the current VUCA world, supply chain disruption is a viral concern to businesses and experts. How to make an effective and efficient plan and by which approach, these questions are highlighted during trade development. Just in time, Lean methods and MRP are familiar to planners, managers, and scholars, and these are applied to millions of companies as their leverages. Meanwhile, there are disadvantages in risk and uncertainty as in setting up a buffer level. Demand-driven material requirements planning (DDMRP) is a new approach strategy applied in international corporations, which has demonstrated advantages compared with previous approaches in setting up cushion levels and avoid in astonishing disruptions. In this case study about ToTo Vietnam, we investigate how the material requirements planning strategy is applied and its benefits and drawbacks. After that, we will continue to analyze the DDMRP approach in the company to contrast and clarify whether they are effective in this case study. This study could be a reference for the company to drive its organization in the current complex supply chain and in the context of expanding operations.

INTRODUCTION

Manufacturing companies are normally directed with an approach to optimal production capacity with minimum resources using and just-in-time, lean production has become familiar to most planners and managers. However, these approaches sometimes could be a trade-off for the company in case it has wrong forecast demand or in the volatility, uncertainty, complexity, and ambiguity (VUCA) world. How to produce goods and services efficiently and effectively is a question for any firm and must be tackled by strategic planners and managers. Lean production and Just-in-time strategies are widely applied to exploit and boost the efficiency of operation resources management.

On other hand, in recent years with many disruptions even in operations and supply chain, affected by political events such as Brexit, the trade war between the USA and China, and covid-19 pandemic, … it raised the requirement to deal with customer demands, logistic and supply chain processes. The probability of logistics and supply chain disruption, and unstable material requirements planning lead to the risk of redundant and costly inventory. In contrast, product life cycles tend to be shorter than before and higher demand for product variety parallel with prod customization and technology development. As the consequence, decision-makers are alerted to be cautious and respond immediately to any sudden events in the processes of material planning. Material requirements planning is a crucial management concern for all economic entities in any sector of the economy because it directly impacts the operation efficiency of the company and customers' needs. Economic and geopolitical conflicts and the skepticism of strategic managers regarding globalization create the highlight of the shifting global value chain as regional and localization in Europe and Asia. Some country in Asia as Vietnam is considered as a country that has many opportunities to develop thank to the trend of manufacturing shifting of giant corporations from China to Vietnam. However, the suppliers and customers of these corporations are in the USA or other strong nations in Europe. Therefore, issues of the global supply chain in logistics and operations management remain with all companies either established in Vietnam or relocated. In this case study, we are going to investigate a branch of a Japanese corporation which are located in Vietnam and cooperates with other branches, suppliers, and customers in China, Japan, and American and Europe markets.

Toto Vietnam is facing the same mentioned risks as many other companies in operation and supply chain management and strives to optimize material requirement management by constant incremental innovation in each division and department. These improvements contributed to the optimization of materials and resources in a short time but were inevitable with systematic risks such as the complexity of the international supply chain and the trend of localization. These impacts are confirmed by the considerable decrease in return on asset performance, fluctuated demand, shortage in manufacturing materials as the consequences of logistics disruption during the pandemic covid-19, and higher material costs from the trade war between USA and China. As highlighted issues, the board of directors (BOD) directed an urgent need for a systematic strategy focused on resources and materials management to cope with the situation of material shortage in risky and long-term sustainable development.

As mentioned, this study aims to analyze the recent production strategy of Toto Vietnam focusing on material requirements planning to investigate the advantages and drawbacks of conventional strategy by applying heuristics analysis. After that, the researcher continues with the DDMRP approach with several experiments to analyze the appropriateness of this method in inventory management with a focus on cushion level in any situations caused by the delay with different ordering lead times. Finally, from these investigations, we propose a reference strategy to the company managers in order to develop a precise approach to material requirement planning.

CHAPTER 1 LITERATURE REVIEW

This chapter represents works of literature that the researchers used to find out the appropriate research methodology for this research.

1.1. Demand forecasting in production

Demand forecasting is a crucial function in decision strategy management it includes activities of prediction and estimation amount of future expected products and it is affected by frequent changes in the economy, technology innovation, and customer preferences (Talib & Yi, 2009), (Archer, 1987). According to (Ptak & Smith, 2016) further forecast, the more inaccurate in the circumstance of volatility, uncertainty, complexity, and ambiguity. Precisely decisions in supply chain and operation management prerequisites a variety of criteria such as intermediaries' forecasting through market research analysis, and technology innovation, while inventory replenishment requires a precise analysis of each stock keeping unit (SKU) lever at production. On another hand, operation and supply chain faces risks associated with both supply chain coordination risk as long as day-to-day management and disruption risks due to natural disasters or systematic risk (Jacobs & Chase, 2018). It is difficult to forecast exact orders from customers to prepare material and combine with accumulated lead time decision-makers must be prudent in information selection and analysis approach to guarantee the most accurate MRP and sufficient with their strategy. Therefore, accumulating forecast information across levers and time series analysis dimensions to obtain thorough data is applied in any field and management level (Babai, Boylan, & Tabar, 2022). There are a variety of forecast methodologies with distinct advantages and disadvantages, strategists must integrate the strengths of techniques to create an appropriate hybrid strategy for the company industry (Aburto & Weber, 2007). Strategists traditionally apply statistical methods as model-based, but it has issues of inaccurate future estimations and is possible to develop. Recently, the application of artificial neural networks in sale forecasting increases contributes to eliminating these issues (Mathew, Nair, & Joseph, 2013).

Demand forecasting is the first process, and it is one of the most important in supply chain management. The more prudent and integrity forecast, the more efficient production, inventory management, operational efficiency improvement, and return on investment. Demand forecasts precisely prevent MRP nervousness and the bullwhip effect; by combining experience performance and forward demand planners can have better decision making in issuing orders, allocation of resources, replenishment of inventory, and more efficiency in inventory cost management (Talib & Yi, 2009). However, it is difficult to forecast accurately demand in the future and risk probability requires planners and managers to be cautious when dealing with forecast steps to satisfy customer demands and advantages in competitive dimensions while interfacing with changes in customers' preferences, technology development, and economic and social environment…etc. Safety stock tackles these changes and requirements in lead time or even in fluctuating lead time (Buzacott & Shanthikumar, 1994).

1.2. Production mix strategies

Recently, operation and supply chain strategies are targeting to reach the triple bottom line in social, economic, and environmental criteria (Jacobs & Chase, 2018). Sustainable development has developed and expanded in a variety of industries and firms scale in both international corporations and small and medium companies. Nowadays, economic entities not only focus on economic interests but are shifting the concentration to the other related perspective of the ecosystem as the higher customer demand. Technology innovation advanced productivity but lacks social and environmental concern as the technology obsolesces. As the consequence, the need for a standard principle must be populated and utilized to balance the triple bottom line.

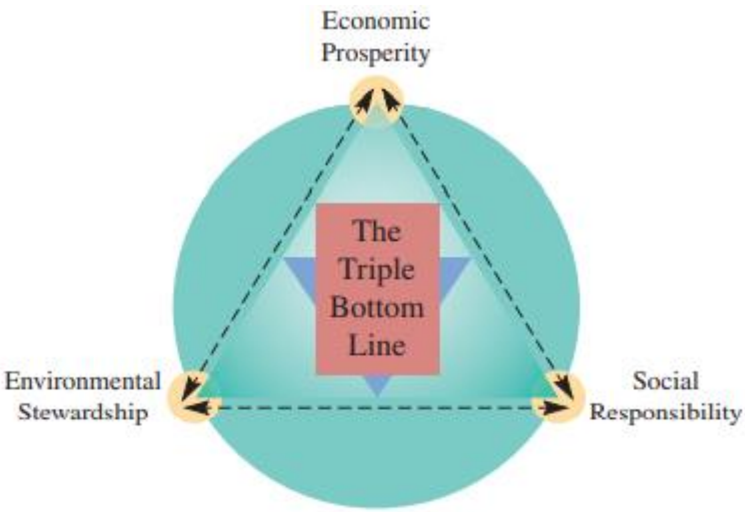
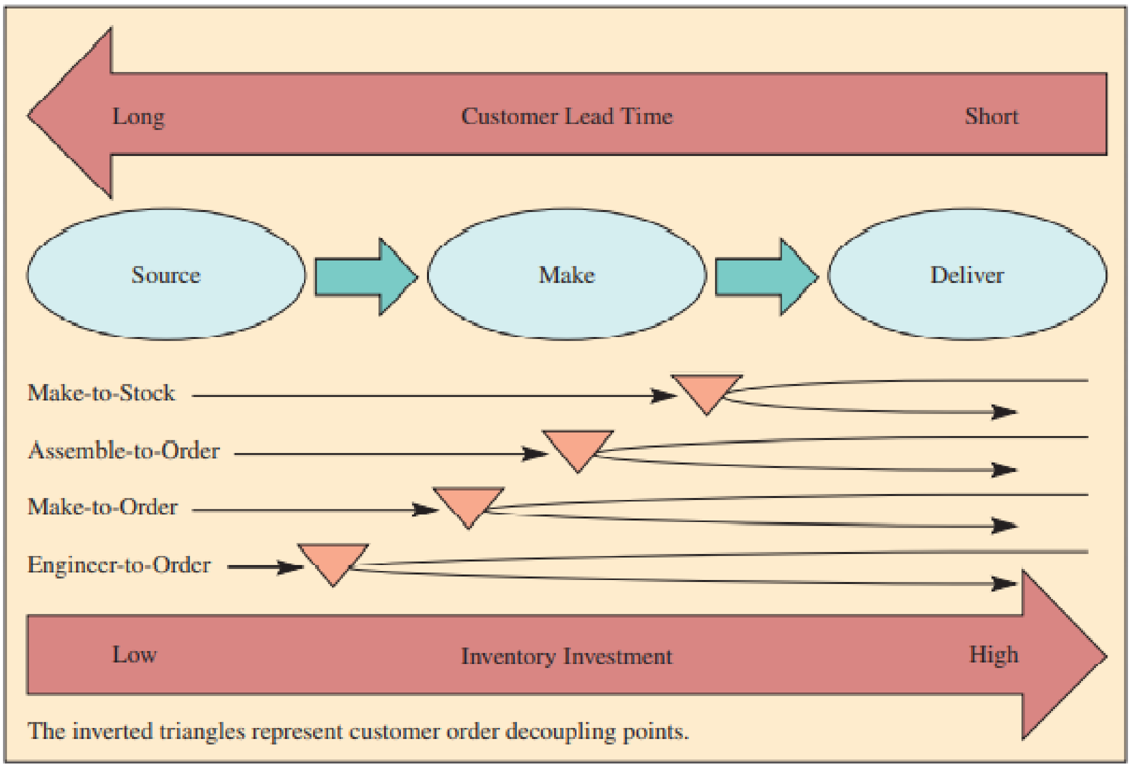


Figure 1. 1: Triple bottom line (Jacobs & Chase, 2018).

As mentioned, firms faced competitive challenges in rapid response to customers' demand and cost management as the preferences changed as the lead of technology development. Based on different industry characteristics, business conditions, and competitive capabilities of each company, each company will have different manufacturing strategies((Miler & Roth, 1994) and each production plan can adopt its specific technology and product strategy as contextual performance, it is not obligated to apply the same product strategy and technology across destinations (Michiya, Garrido-Vega, Jimenez, & Luis, 2015). Several production strategies have been developed for the fulfillment of demand such as Make-to-Stock (MTS), Make-to-Order (MTO), Assemble-to-Order (ATO), and Engineer-to-Order (ETO). Depending on the strategy of the company and its manufacturing capacity and customers' requirements, each company can its inventory positioning. Each strategy corresponds with its customer order decoupling point. While the make-to-stock strategy utilizes "build ahead" based on prediction and historical data to guarantee inventory as demands and reduce waiting time, make-to-order is based on an actual confirmation purchase order from customers to catch instance preferences, but customers' order lead time takes longer. Assemble to order improves this drawback, but as with other strategies, managing inventory efficiency remains critical for any entity. The figure below illustrates the order decoupling point respectively with each production strategy.

Figure 1. 2: Position inventory in the supply chain (Jacobs & Chase, 2018)



Many studies have confirmed that it is not easy to meet all criteria of different market segments. It is necessary to consolidate analyze of market requirements, and the production system as a matrix system to match these demands and competitiveness. In addition, manufacturers' pressure of delivery velocity utilized a make-to-stock production strategy, and a make-to-order strategy corresponds with low-cost criteria. Conventional production strategies apply a hybrid production strategy to eliminate the impact of a single approach, guarantee lead time in the context of uncertain demand, and optimize these advantages as made to forecast production strategy (Meredith & Akinc, 2007) (Kuthambalayan & Bera, 2020). This hybrid strategy is adopted and coordinated in the planning of sales, logistics, and procurement activities to fulfill market demand and remain competitive and mid-term targets (Pereira, Oliveira, & Carravilla, 2022). The production strategy is the backbone to prepare requirements material.

1.3. Production strategy with conventional MRP and DDMRP

Requirement material planning is fundamental to operational activities and in manufacturing or commercial firms, and inventory position strategy contributes significantly to operating efficiently. Inventory turnover is an indicator to measure operational efficiency. High turnover inventory increases operational effectiveness and optimal inventory management performance. However, if a high inventory strategy is leaned out company will face shortages frequently and extremely in any supply chain disruption events. On the other hand, if the company has a low inventory turnover and a high stock position, it will face the situation of obsolete items as changing customer preferences and technology development. Sometimes, in normal circumstances of material requirement planning, a planner will issue a new order when there is any shortage as nervousness, and as a result, after this disruption is solved if the company cannot cancel the previous order, it creates a redundant inventory position and bullwhip effect. How to manage and place an appropriate range of inventory positions not only based on planner experience but also request to choose the right strategy. In industrial revolution 4.0, in the manufacturing world, it is necessary to have a proactive approach to any type of product (Eifler, Mahon, Howard, & Murthy, 2018).

The material requirement planning (MRP) technique is developed based on forecast demand and bill of material (BOM) as long as different components and subcomponents seem extremely complicated when there is any disruption in operations and the supply chain. While Lean production and Just-in-time methodology target production efficiency and minimize waste as a pull system. However, this execution tool has drawbacks of customer tolerant lead time. Both systems have their advantages and drawbacks. Integrating a hybrid system can be a solution to optimize each system's strengths and eliminate its weaknesses to have a better production schedule and control materials requirements (Lee, 1993).

"Genichi Taguchi, a statistician, developed the Taguchi loss function which indicates the variation range increase will lead to increase customer dissatisfaction" (Lean Six Sigma definition, 2022). After that, this function is applied widely in production management and other services. Taguchi loss function and bimodal inventory distribution visualize the importance of operational inventory: too little or too much inventory will be costly. If the firm cannot find an optimal range it will miss sale demand, face customer tolerance, and costly inventory requirements. Figure 1.3 represents the inventory value Taguchi loss function.

When inventory in the range of green is optimal, out of this range inventory and buffer lever will be in a warning situation and the planner must issue replenish orders.

Figure 1. 3: The inventory value loss (Taguchi) function illustrated *(Ptak & Smith, 2016)*

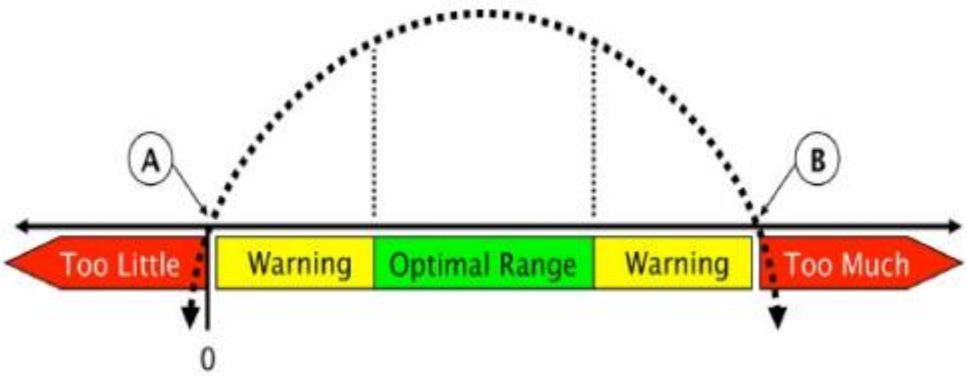


Figure 1. 4: Tighter ranges of inventory range overtime *(Ptak & Smith, 2016)*

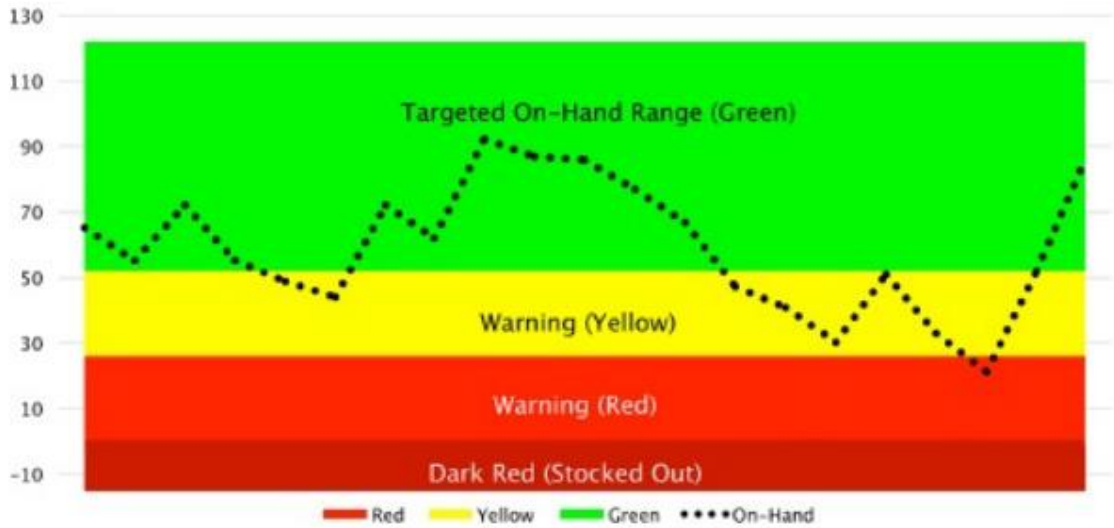


Figure 1.4 shows the tighter ranges of inventory and buffer lever over time in addition to the situation of stock out with dark red color and low on-hand inventory. The state of buffer and on-hand stratified as the green zone is targeted on-hand and buffer lever. In this zone, the on-hand amount and buffer lever will cover the demand if there are uncertain events. While the yellow range is the primary warning, the red zone indicates the situation of stock-out, and dark red is the situation of reaching out of stock. Planners must respond immediately to

replenish inventory in this range. In this status, the company is out of production capability to serve customers' demands.

DDMRP according to Ptak and Smith deals with 3 areas: Position, Protect and Pull with 5 consecutive phases in figure 1.5. The initial important phase is Strategic Inventory Positioning, where to position decoupling points(position); Buffer Profiles and Levels to determine how to optimally dimension buffers (Protect); Dynamic Adjustments defines how to modify buffer levels dynamically (Protect); Demand Driven Planning represent how to generate optimally the scheduling of orders (Pull); Visible and Collaborative Execution manages the flow of materials and information (Pull).

Figure 1.5: 5 phases of DDMRP (Ptak & Smith, Demand Driven Material Requirements Planning (DDMRP), 2018)

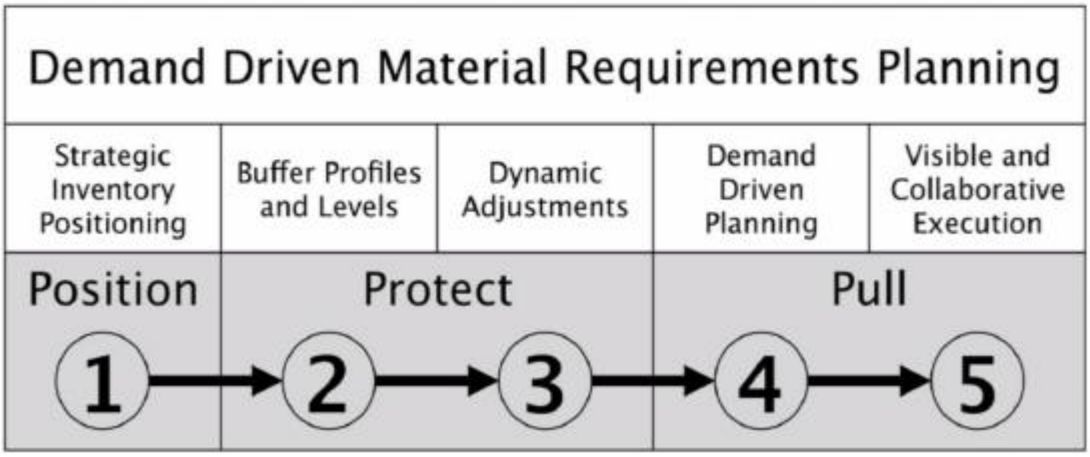
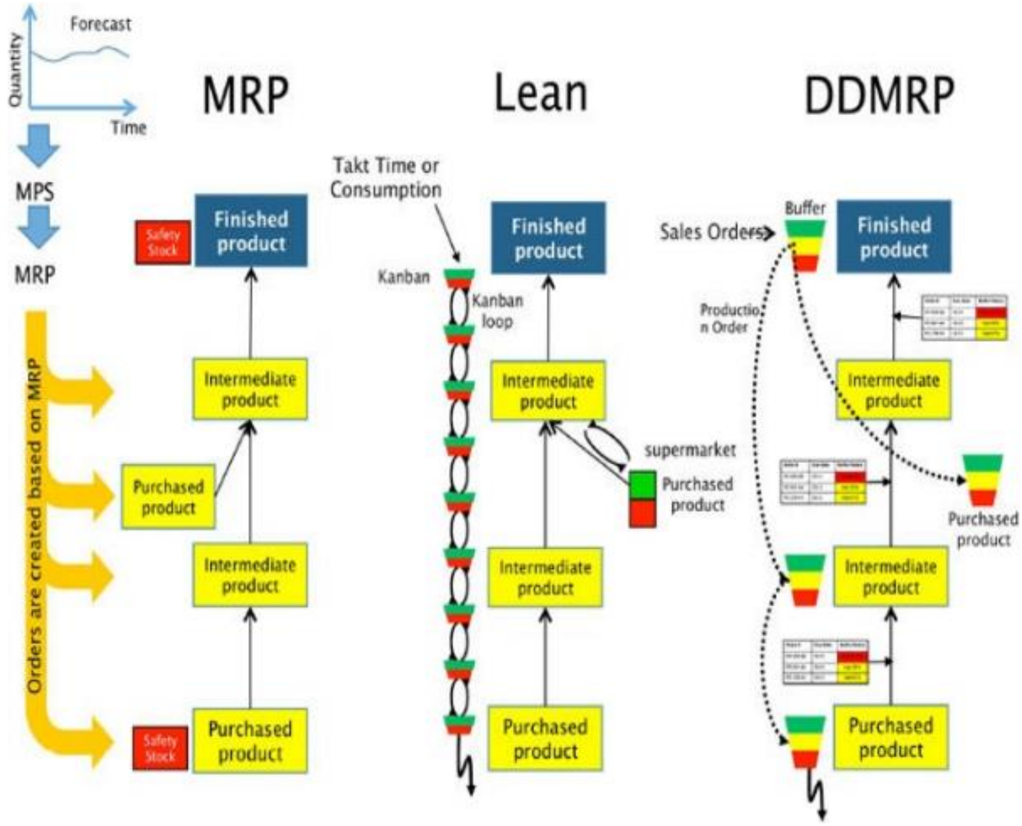


Figure 1.6: Comparison of conventional MRP, Lean, and DDMRP (Ptak & Smith, 2018).



Conventional MRP's fundamental target is to serve all stock positions as indicated in future demand. A master production schedule for material requirement planning creates a detailed synchronized purchase order lead time and quantity as a bill of material components hierarchy. Cushion inventory can remain as original material or finished goods. On another hand, the LEAN approach creates an inventory independence position known as the Kanban position at each point and material planning as a prediction of future demand and history consumption in which the Kanban scope is based on the takt time rate. Kanban and loop coordinate to indicate production decisions. MRP inventory is dependent on both higher levels of demand analysis and downstream processes which is risky for nervousness ordering, while LEAN seems too simple as an independent inventory hierarchy but lacks cushion demonstration. DDMRP utilizes a "decoupled explosion" to guarantee the independent inventory of each production process and fulfill the drawbacks of conventional MRP and

LEAN. This crucial characteristic of DDMRP against nervousness ordering and bullwhip effects at decoupling points when there are changes at a higher level of BOM. A decoupling point is a cornerstone to protect and promote material and related information. MRP without decoupling everything will go as same as predicted, in DDMRP with decoupling everything will change if there are any uncertain events occur. Figure 1.6 illustrates the comparison of material requirements of MRP, LEAN, and DDMRP hierarchy. DDMRP independent planning horizons between decoupling points diminish the variance of demand and supply as synchronization. Order flow as dashed arrows down streams as decoupling points and visible buffer positions enable any correction.

CHAPTER 2. ANALYZE PRODUCTION STRATEGY AND RESEARCH METHODOLOGY

2.1. Conceptual framework

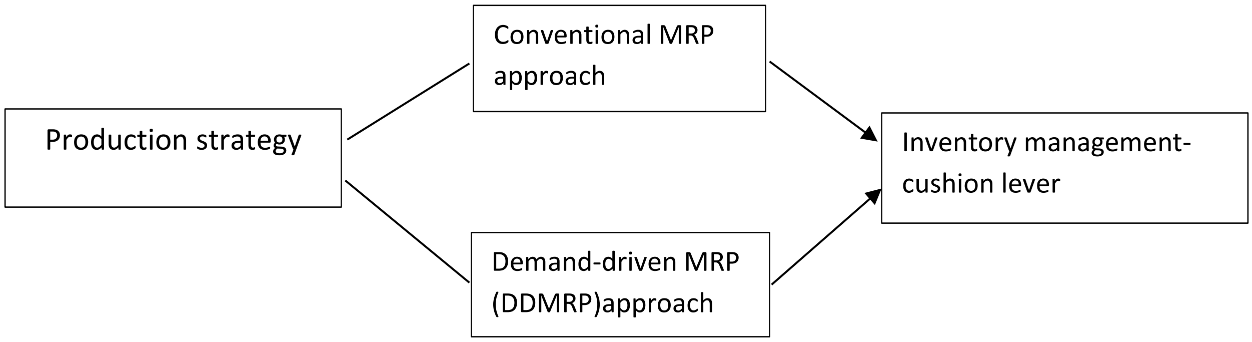


Figure 2. 1: Conceptual framework of the study

Figure 2.1 above indicates analyzing approaches of material requirement planning as the company product strategy. Apply these two methods in experiments based on company demand data to measure the efficiency of the company inventory management in general and emphasize the cushion lever.

2.2. Research design

This case study research utilizes a quantitative approach to analyze the company product strategy and the efficiency of material requirement planning strategy emphasizing cushion level throughout analyzing single items with different characteristics in lead time, demand, and other ordering costs. Primary quantitative data will be applied to analyze production patterns and MRP strategies. This fact-finding scheme is designed to enable the researcher to interpret the gathered data and information and the results adequately and accurately.

The research aims to analyze production strategy and its MRP tactics to measure the efficiency of inventory management and buffer levers in uncertain situations. Primary data will be collected from the original production data system of the company to guarantee accuracy and prudent research analysis.

2.3. Data Processing and Analysis

After collecting the data, the researcher received a variety of rich information and distinguish manufactured parts based on their characteristics of lead time as long, medium, or short to evaluate MRP efficiency.

The target of the research is to determine an MRP strategy that can optimally inventory management which emphasizes the cushion lever in an uncertain situation, the researcher applies the Heuristics method (silver meal, least unit cost, part period balancing) and Wagner Whitin to simultaneously analyze conventional MRP and DDMRP.

2.3.1. Heuristics method

Heuristics methods utilize when demand is not stable in time. While Silver Meal heuristics apply to find a solution that minimizes period cost, least unit cost represents the aim to find local that each unit cost is minimum, and part period balancing target to find the local ordering policy where ordering cost equals holding costs.

We consider the following assumptions:

K: fixed reorder cost.

h: unitary holding cost (per period).

r_j: demand to be met during the j^{th} period.

We can compute G(T), the average cost (per period) if the current order spans the next T periods as below:

Heuristics silver meal method:

G(1) = K

G(2) = (K + h r_2)/2

G(3) = (K + hr_2 + 2 h r_3)/3

…

G(j) = (K + hr_2 + 2 h r_3)+ … + (j – 1) h r_j) / j

Heuristics least unit cost:

G(1) = K/r_1

G(2) = (K + h r_2)/(r_1 + r_2)

G(3) = (K + h r_2 + 2 h r_3)/(r_1 + r_2+ r_3)

…

G(j) = (K + h r_2 + 2 h r_3 + … + (j – 1) h r_j)/(r_1 + r_2 + … +r_j)

Heuristics part period balancing:

|K - G (j)|

Whereas heuristics method the optimal local when: **G (j_0 – 1) > G (j_0) & G (j_0) ≤ G (j_0 + 1)**

2.3.2. Wagner Within the method

This is an exact method; it requires knowing the exact demand of entire horizon periods.

We consider the following assumptions:

K: fixed reorder cost.

h: unitary holding cost (per period).

r_j: demand to be met during the j^{th} period.

c_{ij}: ordering cost and holding cost related to a lot that satisfies the demand for periods ranging from i to j-1:

C_{12} = K,

C_{13} = K + hr_2,

C_{25} = K + hr_3 + 2hr_4,

…

With the T period, we must calculate cost c_{ij} as a minimum summary of:

$C_{1i_1.}$ + $C_{\dot{v}_1 i_2}$+ $C_{i_2 i_3}$+ … + $C_{i_k i_{T+1}}$

2.3.3. DDMRP buffer levers

In this study, the researcher applies DDMRP as a model of a data-driven and prudent approach to inventory. According to Ptak and Smith buffer lever is the heart of DDMRP, and each buffer position consists of three zones with different roles and denote by different colors. The red zone guarantees cushion and avoids stock out, the yellow zone help determines order time as demand and the green zone helps calculate the ordering amount. A fundamental DDMRP formula for simultaneous three zones (Favaretto, Marin, & Tolotti, 2021) developed a model with a heuristics approach to single-item dynamic lot-sizing. The researcher applies the following developed formula as three thresholds:

K_t^R= ADU $l\ \alpha\ (1+\beta)$

K_t^Y= ADU $l\ (1+\alpha+\alpha\beta)$

K_t^G= ADU $l\ (1+\alpha+a\beta+a_G)$

Where the quantities are defined as follows:

$- K_t^R, K_t^Y, K_t^G$: simultaneous are thresholds at the red, yellow, and green zone. Ranges identified such from 0 to K_t^R is the red zone, from K_t^R to the K_t^Y is the yellow zone, and from K_t^Y to K_t^G is the green zone.

- l: lead time

- Risk factor = RF= $a(1+\beta)$; α is the risk related to lead time and β is the risk related to demand (Favaretto, Marin, & Tolotti, 2021).

$\alpha_G \in [0,1]$: as a minor risk of the green zone, close to 0 if the lead time is long, and close to 1 if the lead time is short. It is a calibration of decoupling lead time relation (Favaretto, Marin, & Tolotti, 2021).

In this case study research, the author will apply short, medium, and long lead time, a_G respectively are 0.9, 0.5, 0.1 as a hedge for hedging to bias and intuitive; and propose another option 0.9, 0.8, 0.7 respectively with short, medium, and long lead time.

- ADU: Adjusted daily usage, defined as: $\text{ADU}(t) = (d(t) + d(t+1) + \ldots + d(t+\tau))/\tau$

τ is the number of periods considered

The researcher will utilize all above mentioned related principles MRP and DDMRP with the model developed and evaluated by scholars in this case study to analyze the status of recent company strategy in the next chapter.

CHAPTER 3: ANALYSIS RESULTS AND DISCUSSION

In this chapter, the researcher is going to analyze and understand the company's product strategy. After that, she investigates the effectiveness of MRP by analyzing conventional MRP with heuristics and exact methods. DDMRP approach will be also investigated with three different perspectives to scrutinize DDMRP and MRP with various items which have delayed; toward deeper into high risk of the DDMRP green zone; and very long lead time items.

3.1. Company Introduction

Toto is a Japanese corporation established in 1917 in the ceramics industry with 24 branches in Asia, America, and Europe. Toto Vietnam was established in 2002 until now it had expanded to 4 factories and is constructing the fifth factory and the inventory management system is becoming more complicated than before. The company's operation philosophy is to constantly improve and contribute to society and the environment.

Vision: "Toward a dynamic, vibrant, and excellent Toto" (Toto, 2021).

Mission: The company strives to improve life quality, human rights, and the environment as the global trend at this time.

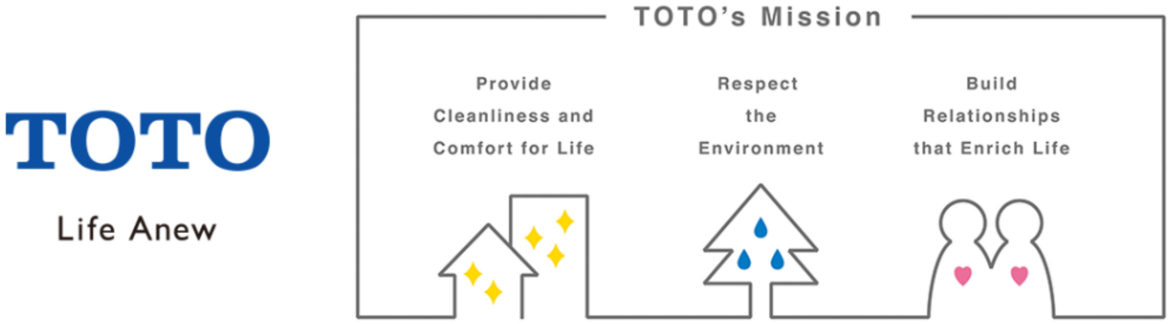


Figure 3. 1: Toto Vietnam mission (Toto, 2021)

Products: the company manufactures and assembles diverse bathroom equipment such as toilets, faucets and showers, lavatories, bathtubs, and other accessories. (Totovn, 2022).

Markets: Toto Vietnam produces to serve both domestic and export, while export accounted for major of the revenue. The company is striving to increase its domestic market share; however, Vietnam is a developing country so with a high pricing strategy the company cannot become a domain branch in Vietnam. The main export markets such as China, Japan, the EU, and America. The company is striving to have lower production costs compared with other corporations' branches to get competitive advantages. Many efforts to improve inventory and other resources have been proposed and experimented with to investigate an optimal approach.

3.2. Company production strategy analysis

3.2.1. General production strategy

With some specific characteristics inside the company and general in the ceramic industry, the company combines both crafts and automatic systems in manufacturing and follows a just-in-time (JIT) production approach. JIT production coordinates with other management activities such as human resources, accounting and finance, sale, and marketing… contributing to improving efficiency and effectiveness in company performance and boosting the company competitiveness (Matsui, 2007). While mainly in the automatic system and only crafts with a small order for R&D and specific and few order quantity. The company applies a diversified inventory strategy, while with domestic market mainly applies to make-to-stock, and export markets mostly with make-to-order. Assemble- to- order, normally applied with accessories products, and finally engineer- to- order with some typical products for R&D or specific project.

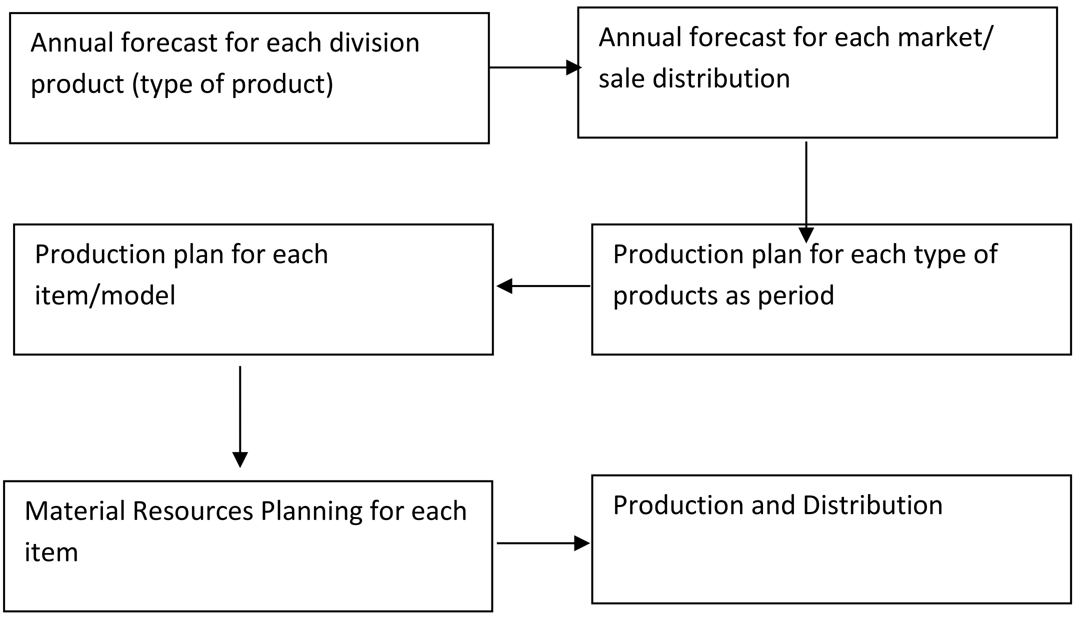
3.2.2. Production forecast

A production budget is created for all fiscal periods by combining sale order forecasts from the sale and marketing divisions. The supporting evidence for this is accounted by the seasoning experience because in some Asia markets like China or Vietnam, where there is a traditional culture of decorating the house to welcome a new lunar year. They will repair or renew furniture in their house to wish a new year with new initiatives and success, this is also a reason why the company has a promotion campaign at the end of the fiscal year. Toward with production schedule combined with demand from customers. Because the majority of the company's revenue comes from export, the decision-makers combine social-economic trend analysis and historical data in these main export markets to propose a new budget for potential market growth. For more details, they must be based on the industrial analysis of real estate or construction development direction to create a consolidated budget. Normally the forecast is based on seasoning and historical data combined with any project orders and targets business in coming periods. Overall, production planning is needed to integrate managerial decisions of managerial strategy, annual target, and operation control (Miller & Liberatore, 1989).

The targeted growth is a core direction to allocate resources and the final budget for all fiscal years and go forward to detail in the coming 3 periods (each period is 1 month). Each year will have a semi-annually budget review or crucial change in demand and each month has twice production revise and additional adjustments if needed.

Initial with a forecast from the sale and planning department will launch budgeting processes through all divisions and apartments from manufacture to service after the sale, and in the production process, actual manufacture position and inventory will be adjusted based on actual ordering from intermediaries and final customers. The production planning starts with a sale forecast for all annual product divisions to each product line, from the annual plan to the monthly production plan. With a detailed production plan for each item, the planner prepares MRP and a detailed production schedule. Below is a production planning system figure to illustrate the production planning processes.

Figure 3. 2: The production planning processes.



(Source: Company data, formulated by author).

Annually, the company has 2 promotion campaigns: in this period sale amount increase by 2,3 times as normal. As a result, the company must produce in advance products as forecasted demand as it is over the capacity of the production line. Corresponding with the increase in production amount, the company must increase other related expenses in labor cost, were house…. In addition, the main components order lead-time takes 1 to 3 months, and uneven demand so the company must be conscious of any risks or uncertainty in production planning, they also must revise the production planning strategy base on the coming period as a strategy for promotion campaign is different with a normal period.

Integrate analyzing information from a company we can summarize their production strategy semi-annually each year they have 2 promotion campaigns and revise the budget semi-annually:

The long lead-time for ordering material is a risk for production supply, if there are any dramatic order adjustments will lead to an urgent solution for planners to secure customer demand otherwise manufacturing will be disrupted. We call 6 periods respectively with 6 months semi-annually: **T1, T2, T3, T4, T5, T6**. At **T0** produce for **T1**; **Dx** is the demand (**x** from 1 to 6); **Ix** is stock at **T(x from 1 to 6)**

We have:

- Production plan at **T1= D(T1)- I(T0)**.

During the quarter of the promotion campaign, sale volume soar in these months, and decision-makers have to adjust the production strategy to avoid overproduction capacity and shortage of customers' demand. In the first months of the quarter in April or October, the production division has to start preparing inventory for the promotion campaign. Occasionally, at the initial semi-annual, planners notice a dramatic increase in orders in the promotion period, and over-production capacity in this quarter, they have to the adjust production plan and push increasing production productivity. Consequently, the company must consider and guarantee material cushion inventory to respond to this occasion and adjust its production strategy to the fluctuation of demand.

3.2.3. Inventory and Ordering strategy

As same as many other manufacturing firms, the company exerts to optimize the efficiency and effectiveness of resources and materials. Lean production and JIT are the approaches throughout all production processes and during the MRP system. However, due to long lead time orders and uneven demand, sometimes, they must tackle with lack of material and nervousness ordering, and some points they have over stock. By analyzing with production processes and MRP system we summarize as semi-annually ordering strategy of the company as below:

We call:

l: is lead time order

α: demanded order= NFP= demand at (T+ l) - stock at (T) - in transit at(T) - work in progress (WIP).

PO: purchase order amount at T

We have:

At T order for production demand at (T+ l):

$$\boldsymbol{PO(T)} = \begin{cases} \boldsymbol{n: n * MOQ \geq \alpha, \alpha > 0} \\ \boldsymbol{0} \quad\quad\quad\quad\quad\quad , \ \boldsymbol{\alpha \leq 0} \end{cases}$$

Decision-makers create a spreadsheet as illustrated table in 4.1 to manage the production plan and inventory. Monthly data include estimate data at beginning of the month, at the end of the month data as actual production processes, and buffer data for cushion management.

Buffer ratio based on stock at the end of the month to compare with next period demand and average monthly demand. This ratio ranges from 0 to 1 and can be adjusted as historical data, which helps planners have an evaluation with cushion level of each item base on usage, order lead time, and order condition as minimum order quantity (MOQ). They normally remain ratios of nearly 1 to hedge if there is any delay in the next production period, but this tactic probability leads to a redundancy sometimes. This cushion approach is useful to avoid postponement in production processes, but a high cushion level means a high inventory cost.

Table 3.1: Production plan illustration

Item	Month (T)								
	Estimate at beginning of (T)				Actual at the end of (T)			Buffer	
	Input WH	Production plan	Sale forecast	Stock	Input WH	Sale	Stock	Ratio stock/ADU	Ratio stock/sale forecast(T+1)
A									
B									

(Source: Company data, formulated by author).

In correspondence with MRP activity, planners have to consider the balance and effectiveness of ordering lot size and warehouse. Each order includes material cost, fix ordering cost, and holding cost and those are not constant over time the planner must base on both their experiences and the MRP system to issue any appropriate order to guarantee delivery demand on time.

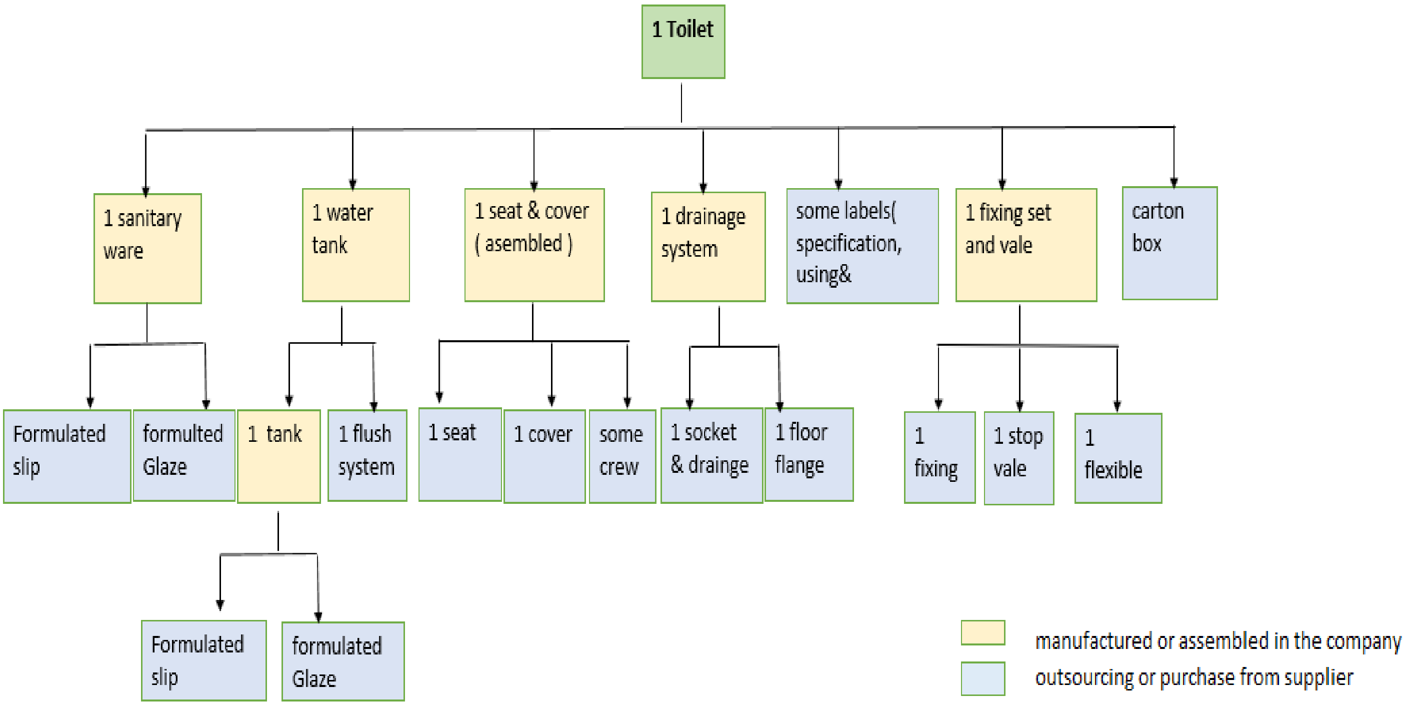
Overall durable products with long lead-time ordering and uneven demand, the company JIT's production strategy faced the issues of under and over stock at some points of considerable changes in demand or the situation of late delivery orders. In this study, we experiment and analyze with DDMRP system with monthly data in a fiscal year to compare which one is the most appropriate method to manage inventory management. After that, we analyze the effectiveness of the ordering strategy with both MRP and DDMRP by calculating ordering cost and inventory. Through this empirical analysis, we can propose an approach for the company in inventory cushion strategy through re-ordering time and lot size with a single item. On another hand, by consolidating both systems each planner and manager will have an appropriate strategy in production planning in the VUCA world.

3.3. Analyze conventional MRP and DDMRP heuristics

3.3.1. Bill of material

The company provides diversified products and applies both in-house produce and outsourcing. The figure below illustrates toilet BOM, one of the main company products.

Figure 3. 3: Toilet BOM illustration

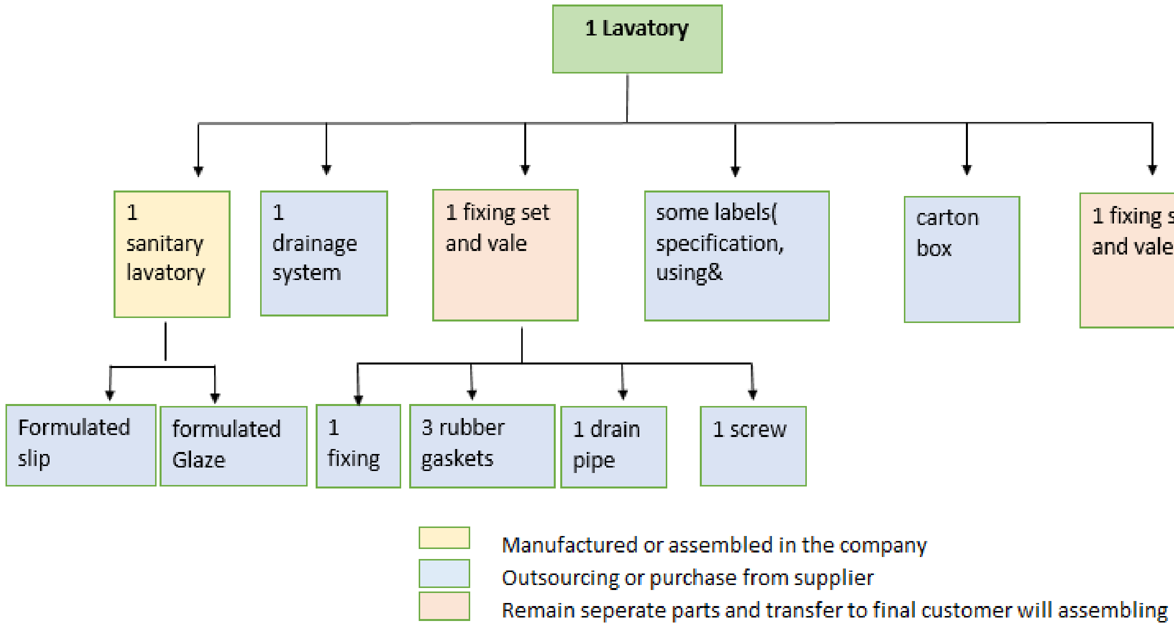


(Source: Company data, formulated by author).

The toilet is one of the durable products and with the strategy of providing qualified and convenient equipment for customers, the company's suppliers are accessed through a long procedure. The company produces and assembles main components, while individual items and raw materials are purchased from suppliers. If there are any inventory shortages or order delays will be the reason for postponing production progress. Production processes with components from raw materials such as sanitary ware, and the sanitary water tank are parallel produced with assembled components such as drainage system, seat& cover.

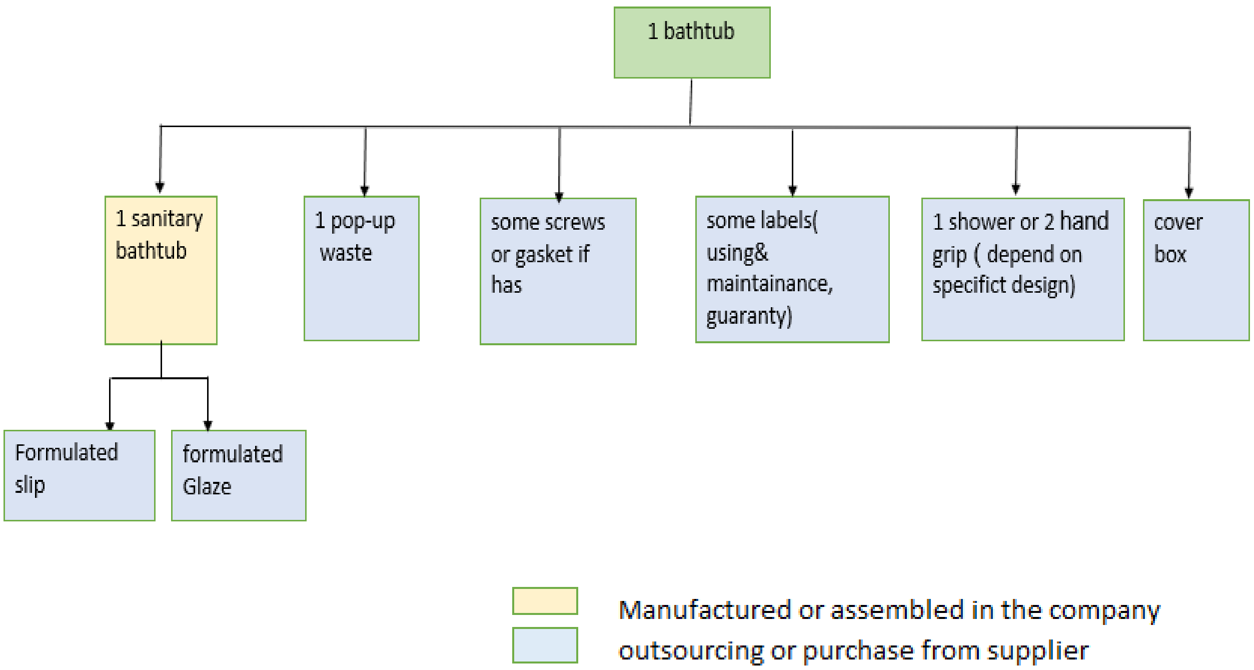
Other types of products such as lavatories, bathtubs, and fand faucets have as same logical BOM and parallel production approach between components produced from raw materials and assembled components.

Figure 3. 4: Lavatory BOM illustration



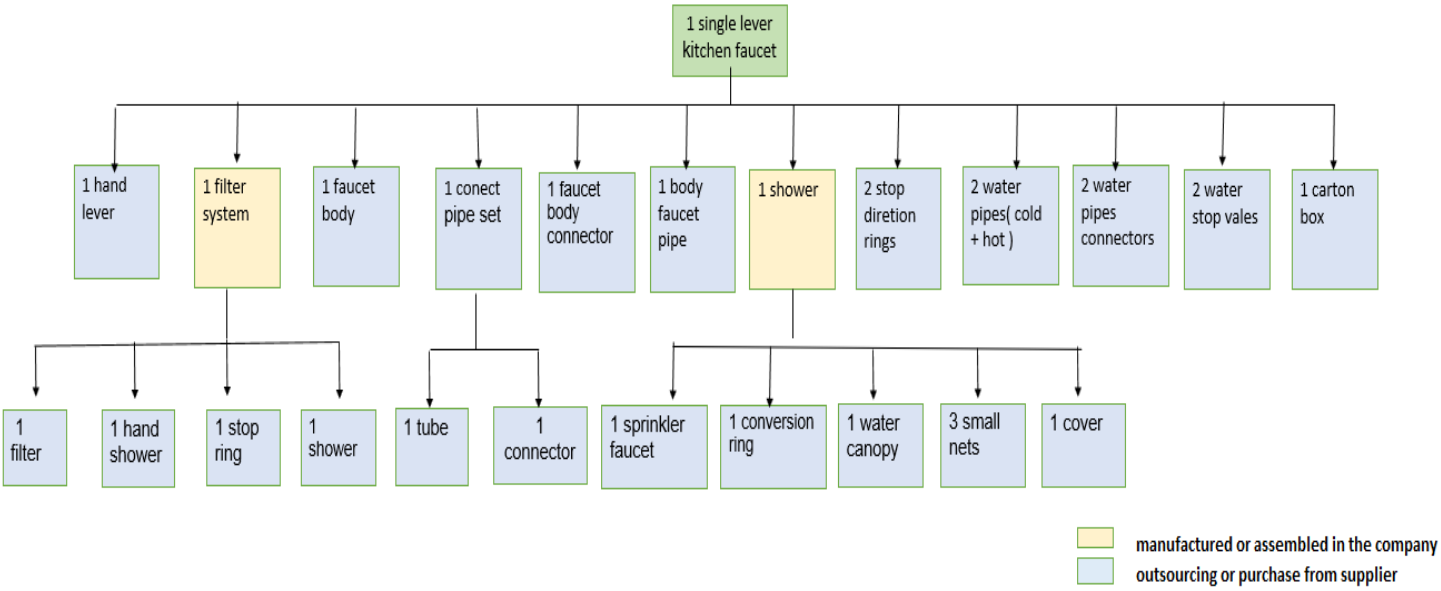
(Source: Company data, formulated by author).

Figure 3. 5: Bathtub BOM illustration



(Source: Company data, formulated by author)

Figure 3. 6:Faucet BOM illustration



(Source: Company data, formulated by author).

3.3.2. Conventional MRP analysis

The replenishment of material in a risky situation is the main target in this section, researcher is going to analyze the MRP status of both oversee and domestic manufacturing parts. In which all single parts have a delivery disruption but without nervousness ordering.

The graphs and tables below illustrate on hand status of single parts which are delayed in the first haft of 2021, which is correspondent with the company semi- annually budget revise; more detail on overall conventional MRP in Appendix A. Coherency with the company strategy if there are any delays, planners avoid nervous replenish inventory. Consequently, the on-hand amount is affected only in the month with disruption and the next period when materials arrived. Overall MRP during subsequent periods and total order amount unchanged and meet demands without redundancy.

Table 3. 2: MRP status of oversea items with delay in the first haft 2021

Item I	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21
	Demand			3,101	3,438	4,319	4,211	13,526	13,526
LeadTime: 1 month	On hand	57		-	-	-	(4,211)	4,211	-
Unit cost= $42.50	Net requirements			3,044	3,438	4,319	4,211	17,737	9,315
On hand: 57	Planned order receipts			3,044	3,438	4,319	-	21,948	9,315
	Planned order releases			3,044	3,438	4,319	4,211	17,737	9,315
	Order cost (USD)			$ 129,370	$ 146,115	$ 183,558	$ -	$ 932,790	$ 395,888

Item II	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21
	Demand			18,824	13,480	10,816	11,688	12,088	10,472
LeadTime: 2 months	On hand	143		-	-	(10,816)	10,816	-	-
Unit cost= $ 15.95	Net requirements			18,681	13,480	10,816	22,504	1,272	10,472
On hand: 143	Planned order receipts			18,681	13,480	-	33,320	1,272	10,472
	Planned order releases	18,681		13,480	10,816	22,504	1,272	10,472	68,104
	Order cost (USD)			$ 297,962	$ 215,006	$ -	$ 531,454	$ 20,288	$ 167,028

Item III	Period	T-(l+1)	T-l	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21
	Demand			3,347	2,395	2,624	3,174	9,765	11,720
LeadTime: 3 months	On hand	84		-	-	-	-	(9,765)	9,765
Unit cost= $35.70	Net requirements			3,263	2,395	2,624	3,174	9,765	21,485
On hand: 84	Planned order receipts			3,263	2,395	2,624	3,174	-	31,250
	Planned order releases	3,263	2,395	2,624	3,174	9,765	21,485	(7,043)	2,276
	Order cost (USD)			$ 116,489	$ 85,502	$ 93,677	$ 113,312	$ -	$ 1,115,625

Table 3. 3: MRP status of oversea items with delay in t Table 3. 4: MRP status of oversea items with delay in the first haft 2021

Item IV	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21
	Demand			**28,492**	**48,294**	**18,534**	**59,283**	**46,235**	**46,374**
LeadTime: 2 months	On hand	154		-	-	-	(59,283)	59,283	-
Unit cost= $42.40	Net requirements			28,492	48,294	18,534	59,283	105,518	(12,909)
On hand: 154	Planned order receipts			28,492	48,294	18,534	-	164,801	(12,909)
	Planned order releases		28,492	48,294	18,534	59,283	105,518	(12,909)	57,231
	Order cost (USD)			**$1,208,061**	**$2,047,666**	**$ 785,842**	**$ -**	**$6,987,562**	**$ (547,342)**

Item V	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21
	Demand			**37,285**	**32,742**	**46,243**	**23,654**	**35,745**	**32,534**
LeadTime: 1 month	On hand	173		-	-	(46,243)	46,243	-	-
Unit cost= $36.30	Net requirements			37,112	32,742	46,243	23,654	81,988	(13,709)
On hand: 173	Planned order receipts			37,112	32,742	-	69,897	81,988	(13,709)
	Planned order releases			37,112	32,742	46,243	23,654	81,988	(13,709)
	Order cost (USD)			**$1,347,166**	**$1,188,535**	**$ -**	**$2,537,261**	**$2,976,164**	**$ (497,637)**

Item VI	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21
	Demand			**13,243**	**35,423**	**42,334**	**23,453**	**23,534**	**42,534**
LeadTime: 3 months	On hand	259		-	-	-	-	(23,534)	23,534
Unit cost= $57.30	Net requirements			12,984	35,423	42,334	23,453	23,534	42,534
On hand: 259	Planned order receipts			12,984	35,423	42,334	23,453	-	66,068
	Planned order releases	12,984	35,423	42,334	23,453	23,534	42,534	47,888	18,819
	Order cost (USD)			**$ 743,983**	**$2,029,738**	**$2,425,738**	**$1,343,857**	**$ -**	**$ 3,785,696**

Table 3.2 and table 3.3 represent principles of MRP in normal ordering conditions with smoothy of reordering procedures, and on time delivery of imported and domestic materials with a different lead time of 1, 2, and 3 months. All these items had a delay in the first half of 2021 with distinguishing order amount and delay period. While some oversea items were delayed in March, April, and May, domestic items had delayed in February, April, and May. The amount of shortage is equivalent exact to the demand for these months. Both imported and national items keep going with the logical of remaining balance inventory at zero and the amount of the reorders tends to equal demand deducted by remaining inventory that that production period and avoid high buffers amount.

In addition, graphs 3.7 and 3.8 visualized the status of on-hand material in the company with a conventional MRP approach with above mentioned items. With both domestic and imported materials, if there is a delay, the production processes are impacted immediately, and inventory slouches under zero with all lead times of 1, 2, and 3 months with oversea material in (-4,211), (-10,816), and(-9,765) respectively. While domestic items have the same lead time dropped to (-46,234), (-59,283), and 23,534 sequences with lead time from short to long. In the next period inventory lines progress to the opposite side of the horizontal axis. Other months without delay the on-hand targeted duplicate to the horizontal axis.

Figure 3. 7: On-hand status of oversea items with the delay

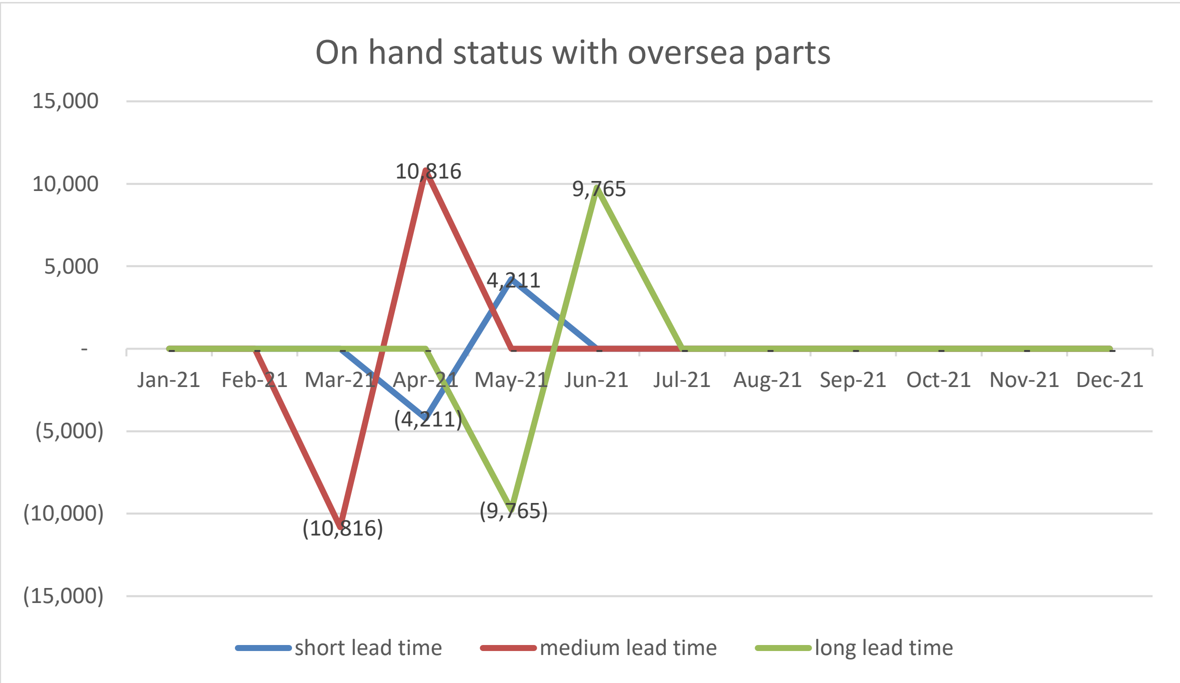
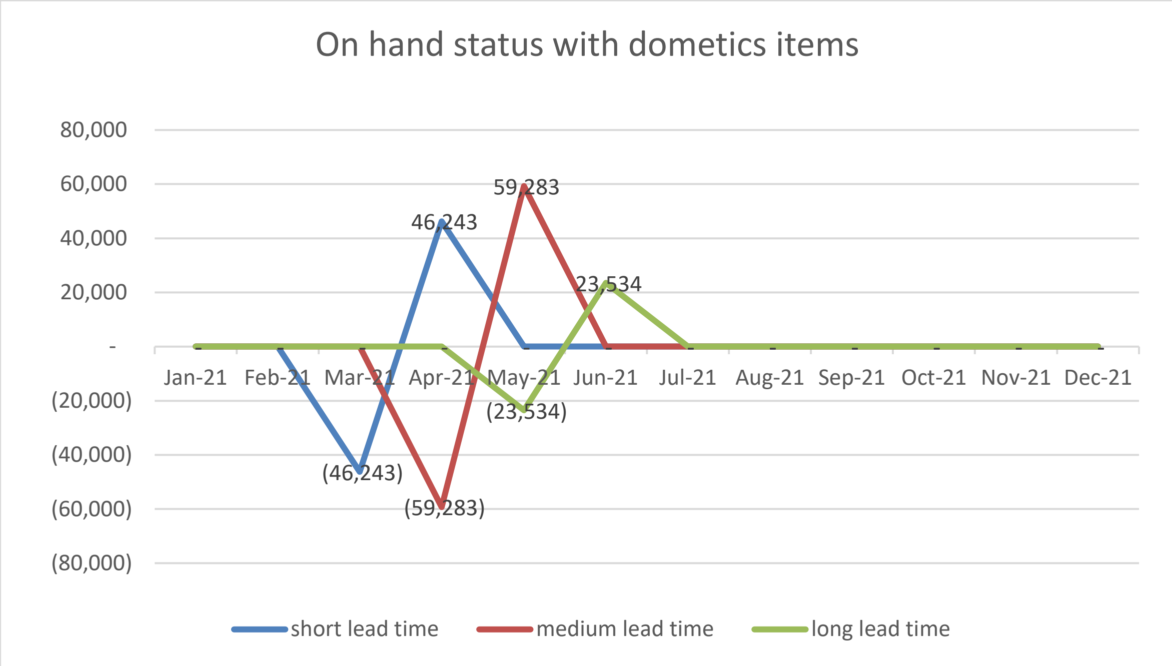


Figure 3. 8: On-hand status of domestic items with the delay



The production targeting materials is to meet the production demand as forecasted by the sale division with minimum waste. Conventional MRP without a buffer contributes to improving operational efficiency, but this is one of the originals shortage materials when there are any ordering disruptions, which is not considerably accounted for in this aspect. The lot-for-lot order strategy is not optimal in uncertain situations, however, without delivery disruption, this approach is either an optimal strategy or not associated with different perspectives. These advantages and drawbacks occur either domestically or oversea with a variety of ordering lead times. Toward this concern, in the next part, the researcher will utilize heuristics and exact methods to investigate the efficient MRP strategy of the company.

3.3.2.1. Heuristics analysis

Table 4.4 below summarizes data of items that are investigated for the optimization of MRP strategy. The company will revise the budget semi-annually we are going to analyze it as a budget periodically. Variety of single items with distinct lead time, unit cost, fix ordering cost(K), holding cost(h), and demand. With this method, we focus on silver meal and Least unit cost analysis to determine the optimal cost as period and unit cost perspectives.

Table 3. 5: Data for analysis

item	I	II	III	IV	V	VI
Leadtime	1	2	3	2	1	3
cost	$ 42.50	$ 15.95	$ 35.70	$ 42.40	$ 36.30	$ 57.30
K	$ 1,134.52	$ 1,446.52	$ 1,134.52	$ 275.00	$ 77.00	$ 98.00
h	$ 0.23	$ 2.50	$ 0.18	$ 0.12	$ 0.27	$ 0.23
Jan	3,101	18,824	3,347	28,492	37,285	13,243
Feb	3,438	13,480	2,395	48,294	32,742	35,423
Mar	4,319	10,816	2,624	18,534	46,243	42,334
Apr	4,211	11,688	3,174	59,283	23,654	23,453
May	13,526	12,088	9,765	46,235	35,745	23,534
Jun	13,526	10,472	11,720	46,374	32,534	42,534

Silver Meal analysis

Table 3.5 shows the result of the first-round silver meal analysis. We can see clearly that there are some items at the initial j0=1 is the optimal ordering strategy to order for the first period. However, for some items (I, III) the optimal option at the second period j0=2 after the order for periods 1 and 2, they must progress evaluation to decide when to order for the following periods.

Item I with a 1-month ordering lead time in December 2020 issues orders for January and February 2021, in February orders for March and April, then in April orders for May, and in May orders for June. Item II with 2 months of lead time, with demands from January 2021 to June 2021 as detailed at table 3.4, the planner should place orders as a lot- for- lot details: in November 2020 process order for January 2021, then in December 2020 order for February 2021, after that in January 2021 orders for March 2021, following in February 2021 orders for demand in April 2021, continue in March orders for May, and finally in April issues order for June. Item III has the same order pattern as item I but with ordering lead time lasts 3 months so in October 2020 planner should issue orders for January and February 2021, in December 2020 orders for March and April 2021, and in February 2021 order for demand in May 2021, lastly in March 2021 order for June 2021. Items IV, V, and VI have as same ordering lot-for-lot pattern as item II, but with items V and VI ordering time change respectively as ordering lead time as 1 and 3 months respectively.

Table 3. 6: The first round of silver meal analysis

item	I	II	III	IV	V	VI
G(1)=	$ 1,134.52	$ 1,446.52	$ 1,134.52	$ 275.00	$ 77.00	$ 98.00
G(2)=	$ 962.63	$17,573.26	$ 782.81	$ 3,035.14	$ 4,458.67	$ 4,122.65
G(3)=	$ 1,304.00	$29,742.17	$ 836.75	$ 3,506.15	$11,296.19	$ 9,239.64
G(4)=	$ 1,704.40	$44,221.63	$ 1,056.06	$ 7,965.08	$13,262.08	$10,975.38
G(5)=	$ 3,852.30	$59,553.30	$ 2,251.00	$10,810.62	$18,330.58	$13,110.56
G(6)=	$ 5,802.74	$71,444.42	$ 3,633.84	$13,646.25	$22,595.63	$19,077.81
Local min:	j0=2	j0=1	j0=2	j0=1	j0=1	j0=1

Table 3.6 indicates the second round of silver meal analysis of the ordering strategy; the optimal logic ordering strategy is the same as the first round. The decision maker must keep forward with this process.

Table 3. 7: The second round of silver meal analysis

item	I	II	III	IV	V	VI
G(1)=	$ 1,134.52	$ 1,446.52	1,134.52	$ 275.00	$ 77.00	$ 98.00
G(2)=	$ 1,063.95	$14,243.26	$ 852.92	$ 1,249.54	$ 6,281.31	$ 4,917.41
G(3)=	$ 2,775.00	$28,975.51	$ 1,740.41	$ 5,575.67	$ 8,445.26	$ 6,874.40
G(4)=	$ 4,414.49	$44,396.63	$ 2,005.65	$ 8,342.90	$13,572.31	$ 9,215.42
G(5)=		$56,461.30		$11,126.22	$17,885.19	$15,198.59
Local min	j0=2	j0=1	j0=2	j0=1	j0=1	j0=1

Tables 3.7, 3.8, and 3.9 show results of optimal local to place order for these final 3 rounds. Overall, the optimal ordering local is at the first time and process order lot- for- lot. While items I and III need to process three ordering generations, the others have to progress five times.

Table 3. 8: The third round of silver meal analysis

item	I	II	III	IV	V	VI
G(1)=	$ 1,134.52	$ 1,446.52	$ 1,134.52	$ 275.00	$ 77.00	$ 98.00
G(2)=	$ 2,122.75	$15,333.26	$ 1,622.06	$ 3,694.48	$ 3,231.79	$ 2,746.10
G(3)=		$30,368.84		$ 6,161.79	$ 8,588.63	$ 5,439.28
G(4)=		$42,411.63		$ 8,795.00	$13,029.61	$11,416.57
Local min	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

Table 3. 9: The fourth round of silver meal analysis

item	I	II	III	IV	V	VI
G(1)=		$ 1,446.52		$ 275.00	$ 77.00	$ 98.00
G(2)=		$13,813.26		$ 2,919.94	$ 4,430.59	$ 4,940.41
G(3)=		$28,008.84		$ 5,650.99	$ 9,098.84	$ 8,358.82
Local min		j0=1		j0=1	j0=1	j0=1

Table 3. 10: The fifth round of silver meal analysis

item	I	II	III	IV	V	VI
G(1)=	-	$ 1,446.52	-	$ 275.00	$ 77.00	$ 98.00
G(2)=	-	$13,813.26	-	$ 2,919.94	$ 4,430.59	$ 4,940.41
Local min		j0=1		j0=1	j0=1	j0=1

In conclusion, with the silver meal method, during 6 periods of first haft 2021, while some items need place optimal order as the lot- for- lot as same as with conventional MRP strategy, some others single items must be applied hybrid order strategy as combine demand in January and February, March and April then continue lot- for- lot order for demands in May and June respectively:

At any good and services levels, order cost could be accounted for as periodically or in detail as unit cost. Different product categories as their own unit cost. Periodically cost calculation avoids miss measure of the uncountable cost, in addition, unit cost measurement advances decision-makers investigate precisely in quantitative. Tackle with this, the researcher's progress with the least unit cost analysis in the successive part.

Least unit cost analysis

The author utilizes the same data that is analyzed in silver meal analysis. Tables from 3.10 to 3.14 present the optimal ordering solution of those materials, which are domestic and imported with order lead times of 1, 2, and 3 months. With details following: Item I at December 2020 issues orders for January and February 2021, in February orders for March and April, then in April orders for May, and in May orders for June. Item II planner should progress orders as lots- for- lot as: in November 2020 process order for January 2021, then in December 2020 order for February 2021, after that in January 2021 orders for March 2021, in February 2021 orders for demand in April 2021, following in March orders for May, and finally in April issues order for June. Item III has the same order pattern as item I but with the orderings lead time lasts 3 months point October 2020 planner should issues order for January and February 2021, in December 2020 orders for March and April 2021, and in February 2021 order for demand in May 2021, lastly in March 2021 order for June 2021. Items IV, V, and VI have as same as ordering lot-for-lot pattern to item II, but items V and VI ordering time change respectively as ordering lead time of 1 and 3 months respectively.

Table 4.10 and table 4.11 represent the results of the first and second rounds of unit cost analysis. According to these tables, both have the same order strategy: items I and III with optimal local at first date orders for the first and the second periods, and other items only order for the first period.

Table 3. 11: The first round of least unit cost analysis

item	I	II	III	IV	V	VI
G(1)=	0.3659	0.0768	0.3390	0.0097	0.0021	0.0074
G(2)=	0.2944	1.0880	0.2727	0.0791	0.1273	0.1694
G(3)=	0.3603	2.0693	0.3001	0.1103	0.2915	0.3046
G(4)=	0.4524	3.2274	0.3661	0.2061	0.3791	0.3836
G(5)=	0.6736	4.4512	0.5283	0.2691	0.5217	0.4751
G(6)=	0.8266	5.5406	0.6602	0.3312	0.6512	0.6341
Local min	j0=2	j0=1	j0=2	j0=1	j0=1	j0=1

Table 3. 12: The second round of least unit cost analysis

item	I	II	III	IV	V	VI
G(1)=	0.2627	0.1073	0.4324	0.0057	0.0024	0.0028
G(2)=	0.2465	1.1725	0.2942	0.0374	0.1591	0.1265
G(3)=	0.3774	2.4157	0.3355	0.1326	0.2468	0.2038
G(4)=	0.4963	3.6942	0.4233	0.1936	0.3923	0.2955
G(5)=		4.8221		0.2543	0.5232	0.4543
Local min	j0=2	j0=1	j0=2	j0=1	j0=1	j0=1

Analyze toward the third round as indicated in table 4.12 of least unit cost analysis, it is undoubtedly concluded in this round the optimal local when ordered only for the coming period.

Table 3. 13: The third round of least unit cost analysis

item	I	II	III	IV	V	VI
G(1)=	0.0839	0.1337	0.1162	0.0148	0.0017	0.0023
G(2)=	0.1569	1.3627	0.1510	0.0950	0.0925	0.0835
G(3)=		2.7189		0.9248	0.8928	1.0915
G(4)=		6.2646		0.3264	0.6472	0.5763
Local min	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

Table 3.13 and table 3.14 illustrate the optimal solution for items that have approached lot-for- lot order strategy. The company order strategy matches this optimal local analysis.

Table 3. 14: The fourth round of least unit cost analysis

item	I	II	III	IV	V	VI
G(1)=		0.1238		0.0046	0.0033	0.0042
G(2)=		1.3319		0.0552	0.1638	0.1173
G(3)=		2.4535		0.1116	0.2969	0.2801
Local min		j0=1		j0=1	j0=1	j0=1

Table 3. 15:The fifth round of least unit cost analysis

item	I	II	III	IV	V	VI
G(1)=		0.1197		0.0059	0.0022	0.0042
G(2)=		1.2246		0.0631	0.1298	0.1496
Local min		j0=1		j0=1	j0=1	j0=1

As all above analyzed, we got the same results by approach heuristics method focus on least period and unit ordering cost. Within the first half of 2021 budgeting, the company can utilize a hybrid order period to get optimal material cost as the lot-for-lot ordering and merge demand of some continuous period against exorbitant material cost. In contrast with company strategy the heuristics analysis investigates the unification with the recently ordered approach, nevertheless, some other single items should employ a hybrid strategy. This approach can be audited by a more precise approach as an exact method.

3.3.2.2. Wagner Within the analysis

Wagner Within is an exact method, which is utilized in this research to scrutinize the appropriateness of the company ordering strategy and prove the results of heuristics analysis. Table 3.15 summarizes the data of single items which are examined.

Table 3. 16: Wagner Within the analysis of data

Item		I	II	III	IV	V	VI
Unit cost ($)		$42.50	$15.95	$35.70	$42.40	$ 36.30	$ 57.30
Number of periods	T	6	6	6	6	6	6
Ordering cost (fixed)($)	K	$1,134.52	$1,446.52	$ 1,134.52	$275.00	$ 77.00	$ 98.00
Holding cost per period (fixed)($)	h	$0.23	$2.50	$ 0.18	$ 0.12	$0.27	$ 0.23
Demand period 1	r1	3,101	18,824	3,347	28,492	37,285	13,243
Demand period 2	r2	3,438	13,480	2,395	48,294	32,742	35,423
Demand period 3	r3	4,319	10,816	2,624	18,534	46,243	42,334
Demand period 4	r4	4,211	11,688	3,174	59,283	23,654	23,453
Demand period 5	r5	13,526	12,088	9,765	46,235	35,745	23,534
Demand period 6	r6	13,526	10,472	11,720	46,374	32,534	42,534

Tables from 3.6 to 3.21 represent the Wagner Within analysis results of different single items with category values. All highlighted local is the optimal ordering points along six periods.

Table 3. 17: Wagner Within analysis result of items

Item I			Matrix for partial costs: cij + f(j)						
			period	1	2	3	4	5	6
f(1)	1,221,585			1,221,929	1,221,585	1,222,603	1,224,374	1,235,684	1,824,959
f(2)	1,089,002				1,089,002	1,089,026	1,089,829	1,098,027	1,684,192
f(3)	941,752					941,918	941,752	946,840	1,529,893
f(4)	757,226						757,226	759,203	1,339,145
f(5)	577,124							577,124	1,153,956
f(6)	1,135								1,135
f(7)	-								-

Total Cost: $1,221,585

Optimal Policy: with 1 month of ordering lead time in December 2020 orders for Jan and Feb; in February 2021 orders for March and April; in April 2021 orders for May 2021, and in May 2021 orders for June 2021. Ordering pattern as same as with Heuristics analysis with Silver Meal and Least unit cost as investigated above.

Table 3. 18: Wagner Within analysis result of item II

Item II			Matrix for partial costs: cij + f(j)						
			period	1	2	3	4	5	6
f(1)	1,049,895			1,049,895	1,082,149	1,134,782	1,220,996	1,366,204	1,662,686
f(2)	748,206				748,206	773,799	830,793	945,781	1,216,083
f(3)	531,753					531,753	559,527	644,295	888,417
f(4)	357,792						357,792	412,340	630,282
f(5)	169,921							169,921	387,459
f(6)	1,447								1,447
f(7)	-								-

Total Cost: $1,049,895

Optimal Policy: order as lot- for- lot pattern with a lead time that lasts 2 months details: in November 2020 orders for demand in January 2021, then in December 2021 orders for February 2021, next in January 2021 orders for March 2021, after that in February purchases for April, toward in March 2021 order for demand in May 2021, and finally in April orders for June.

Table 3. 19:Wagner Within analysis result of item III

Item III

		Matrix for partial costs: cij + f(j)						
		period	1	2	3	4	5	6
f(1)	767,126		767,357	767,315	767,126	836,875	772,978	1,200,796
f(2)	646,734			647,396	646,734	715,913	650,258	1,075,966
f(3)	560,760				560,760	629,367	561,955	985,553
f(4)	465,949					535,119	465,949	887,438
f(5)	420,673						420,673	770,259
f(6)	1,135							1,135
f(7)	-							-

Total Cost: $767,126

Optimal Policy: with a lead time of 3 months, the decision maker should place order details: in October 2020 orders for January, February, and March 2021; in January 2021 orders for April and May 2021, and in March 2021 orders for June 2021.

Table 3. 20: Wagner Within analysis result of item IV

Item IV

		Matrix for partial costs: cij + f(j)						
		period	1	2	3	4	5	6
f(1)	8,522,454		8,522,454	8,527,975	8,532,148	8,553,835	8,569,859	10,563,666
f(2)	7,314,119			7,314,119	7,316,068	7,330,641	7,341,117	9,329,359
f(3)	5,266,178				5,266,178	5,273,637	5,278,565	7,261,242
f(4)	4,480,061					4,480,682	4,480,061	6,457,174
f(5)	1,966,808						1,966,808	3,932,461
f(6)	275							275
f(7)	-							-

Total Cost: $8,522,454

Optimal Policy: From January to March order lot- a for- lot with ordering lead time in 2 months as details: in November 2020 orders for January 2021, then in December 2020 orders for February, and in January place order for demand in March 2021. After that planner should change the ordering pattern as in February 2021 orders for April and May 2021. Finally in April orders for June.

Table 3. 21: Wagner Within analysis result of item V

Item V		Matrix for partial costs: cij + f(j)						
		period	1	2	3	4	5	6
f(1)	6,260,687		6,260,687	6,269,451	6,294,345	6,313,428	6,468,515	7,693,343
f(2)	4,907,165			4,907,165	4,919,574	4,932,270	5,077,705	6,293,749
f(3)	3,718,553				3,718,553	3,724,863	3,860,647	5,067,907
f(4)	2,039,855					2,039,855	2,165,989	3,364,464
f(5)	1,181,138						1,181,138	2,487,389
f(6)	77							77
f(7)	-							-

Total Cost: $6,260,687

Optimal Policy: order lot- for- lot with 1 month of ordering lead time: in December 2020 places an order for demand in January 2021, in January 2021 orders for demand in February 2021, coming with the order in March 2021 to respond to demand in April 2021, and then in April orders for May, and lastly in May orders for demand in June 2021.

Table 3. 22: Wagner Within analysis result of item VI

Item VI

			Matrix for partial costs: cij + f(j)					
		period	1	2	3	4	5	6
f(1)	6,260,687		6,260,687	6,269,451	7,939,983	9,039,453	7,972,306	10,458,320
f(2)	7,153,636			7,153,636	7,163,275	8,257,350	7,184,791	9,661,022
f(3)	5,123,800				5,123,800	6,212,481	5,134,509	7,600,958
f(4)	2,697,964					3,781,349	2,697,964	5,154,630
f(5)	2,437,394						2,437,394	3,795,577
f(6)	98							98
f(7)	-							-

Total Cost: $6,260,687

Optimal Policy: from January to March order lot- a for- lot with ordering lead time lasts 3 months as details: in October 2020 orders for demand in January 2021, in November 2020 issues purchasing order for February 2021, and in December 2020 orders for demand in March 2021. After that, in January 2021 orders for demands in April and May 2021: and in March 2021 orders for June 2021.

According to the above investigated, the ordering strategies are different between single items. The lot- for- lot ordering as conventional MRP is not appropriate for all distinguishing items as proved through heuristics and exact methods analysis. In addition, these verifications are conducted to prove the ordering cost at their optimal locals: some items employ only a lot-for-lot ordering strategy throughout periods (items II, V), and a part of items handle by merging 2 or 3-period demand as a cluster (item III), and others implement hybrid ordering strategy as items I, VI, and IV. In the condition of smoothly ordering and delivering procedures, these mentioned order tactic approaches can be utilized as optimal resolutions. However, it has not been scrutinized the situation of delay or volatility demand. This concern will be tackled in the sequence analysis of DDMRP.

4.2.3. DDMRP approach

4.2.3.1. DDMRP analysis

As mentioned in chapter 3, the DDMRP service levers are defined through three zones namely: green, yellow, and red. Lead time and risk factors directly affect each service lever and lead time has its own risk accounted respectively. Planners can interface with the risk of shortage in service as a lead time, the longer the lead time, the higher risk they must account for. According to the validation of DDMRP heuristics(Favaretto, Marin, & Tolotti, 2021) some references linkage between service levels and lead time could be continue utilized in this case study: service level is 90% and ε = 0.1 if the lead time is short, the service level is 80% and ε = 0.2 if the lead time is medium, and the service level is 70% and ε = 0.3 if the lead time is long. By substitute this value to the formula of DDMRP risk factor we have: ε = 0.1, α = 1.03 and β = 0.25; for ε = 0.2, α = 0.67 and β = 0.16 and for ε = 0.3, α = 0.42 and β = 0.10. As mentioned in chapter 3, $a_G \in [0,1]$ as long as lead time short or long, however, there is a probability of an error assessment this study the researcher supposes if the lead time is short(1 month) a_G=0.9; medium lead time(2 months), $a_G = 0.5$; and long lead time(3 months) $a_G = 0.1$. These data are summarized as bellow:

Lead time	Month	α	β	a_G
short	1	1.03	0.25	0.9
Intermediate	2	0.67	0.16	0.5
Long	3	0.42	0.1	0.1

DDMRP service levers are represented through three zones of green, yellow, and red are directly impacted by the average daily usage (ADU) which is calculated as the average demand for three continuous months. ADU is the principle of average demand, which contributes to hedging fluctuating demands.

To avoid any bias and guarantee historical linkage, the researcher is going to analyze data from the fourth quarter of the previous year (2020) and the first quarter of the following year (2022) to investigate appropriate and then focus on the narrative results of 12 months in the year 2021. The investigation results represented following are after several experiments with different single parts, which are classified based on oversea or domestic items and more specific as lead time order: long, medium, and short.

DDMRP with oversea items

We are going to investigate DDMRP with a variety of oversea items to conceive on-hand and service zones in a smooth condition and a disruption situation.

Short lead time items

Figure 3.9 below represents the positions of DDMRP service levels and on-hand with short lead time materials of oversea items. With the DDMRP approach, the on-hand fluctuated as demand, and the proportion of each zone remains positive without a shortage in production. The on-hand shifting trend is the same as the requirement of order demanding amount. As the short order lead time is 1 month, this approach remains inventory position within the threshold of positive, but it is lower than the top of the yellow zone and picks up equal to nearly 0.5 top of the green zone.

Figure 3. 9: Overseas short lead time utilize DDMRP with and without delays

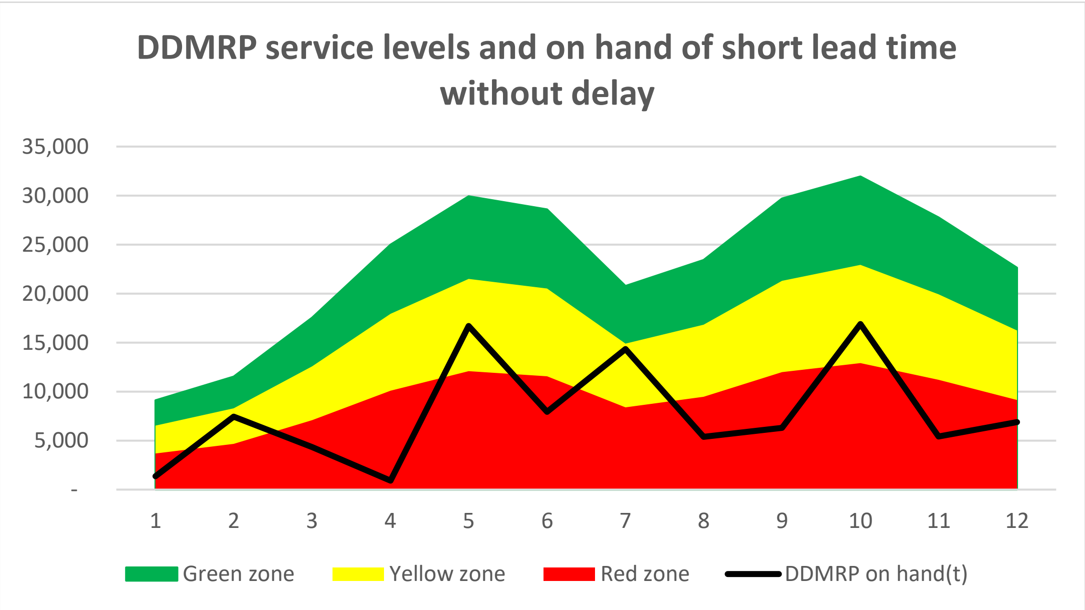


Figure 3. 10: Overseas short lead time utilize DDMRP with and with the delay

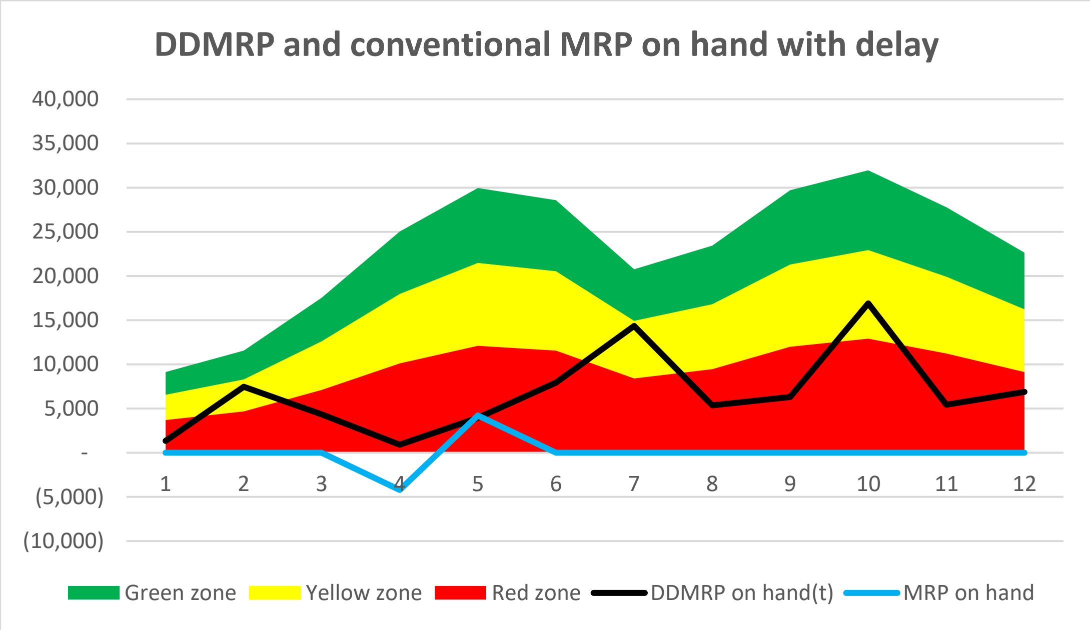


Figure 3.10 compares on hand amount of the same oversea single item with 1 month of lead time when there is a delay in April. From the graph, we can see that, while with conventional MRP, production processes will be affected by lack of production material as same as demand amount of 4,211 parts, DDMRP approach helps the production processes avoid disruption as the buffer of on hand. In the next period, May 2021, on hand position with DDMRP is recovered as the strategic logical with the amount equal to the conventional MRP positive 4,211 parts. These other months' DDMRP approach remains the logic of buffer with on hand amount within the threshold of red and yellow level, while with the conventional MRP principle, there is no buffer remaining.

We are coming up with analyzing of DDMRP buffer levels and on-hand overseas single items with a lead time are 2 months as represented in figure 3.11 and figure 3.12 below:

Figure 3.11 shows the volatility of buffer levels and on-hand position of overseas single items with intermediate ordering lead time when utilizing DDMRP. Ordering lead time in 2 months leads to higher buffer levels and on-hand requirements. On hand materials shifting changes as the trend of the demand during the year 2021. During the period of the promotion campaign in April and November, the higher inventory is appropriate with the increasing demand in these periods. On-hand, position tends to increase in the quarter of the promotion campaign and decreases after that to avoid redundancy.

Figure 3. 11: Overseas intermediate lead time items utilize DDMRP with and without delays

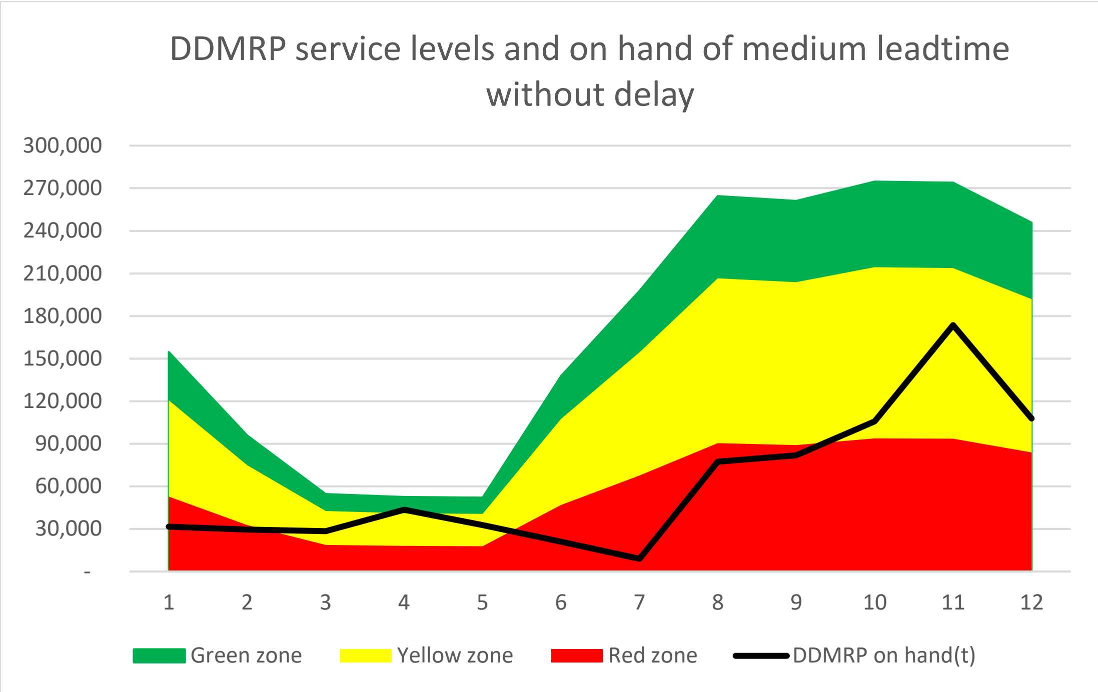
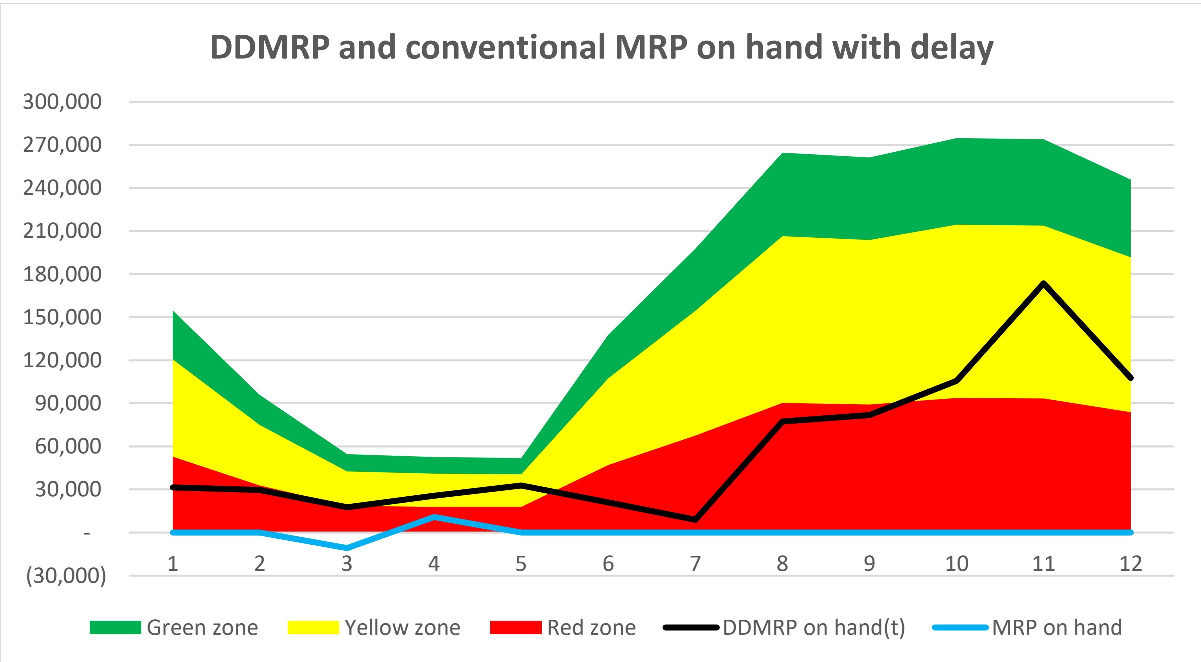


Figure 3. 12: Overseas medium lead time utilize DDMRP with and with the delay



The figure contrast on hand status of intermediate ordering lead time of the same oversea part with figure 3.11 DDMRP remains a buffer inventory to supply to production even in situations of delay in March. The on-hand amount in March reduces the amount as same as the demand of the month at 10,816 pieces, while with the MRP strategy, there is a shortage of the same amount at minus 10,816 pieces. In April, when the delay arrived, the on-hand logic of DDMRP did not change, the amount of inventory remains an appropriate amount at 25,748 pieces but lower than the circumstance without delay. In other months, with conventional MRP target at zero inventory, DDMRP remains a buffer amount as the trend of demand.

From another perspective single items with a long lead time ordering of 3 months, require the planner to pay more attention to the lead time risky. Figures 3.13 represents more detail about buffers of red, yellow, and green and on-hand with DDMRP in normal ordering conditions. As same as with short and intermediate items, a long lead time item guarantees the continuous supply of production materials. It is undoubted to realize that, as the vulnerability of on-hand status linkage with order lead time, the threshold to determine the time to reorder in the yellow zone is high and a minority of reordering amount as the hedge to impact in a situation of delay delivering orders. Once again, on hand position of this part moves as long as with the buffer levels. Before and after the period's promotion, inventory reduces as the demand.

Figure 3. 13: Overseas long lead time items utilize DDMRP without delays

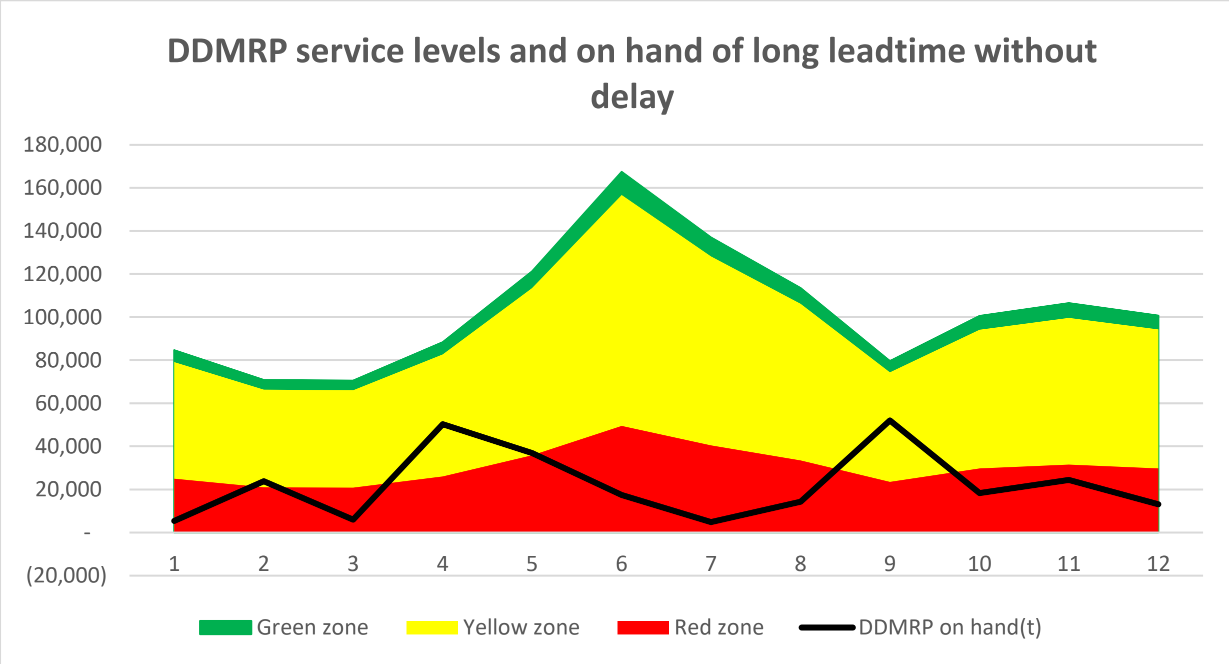
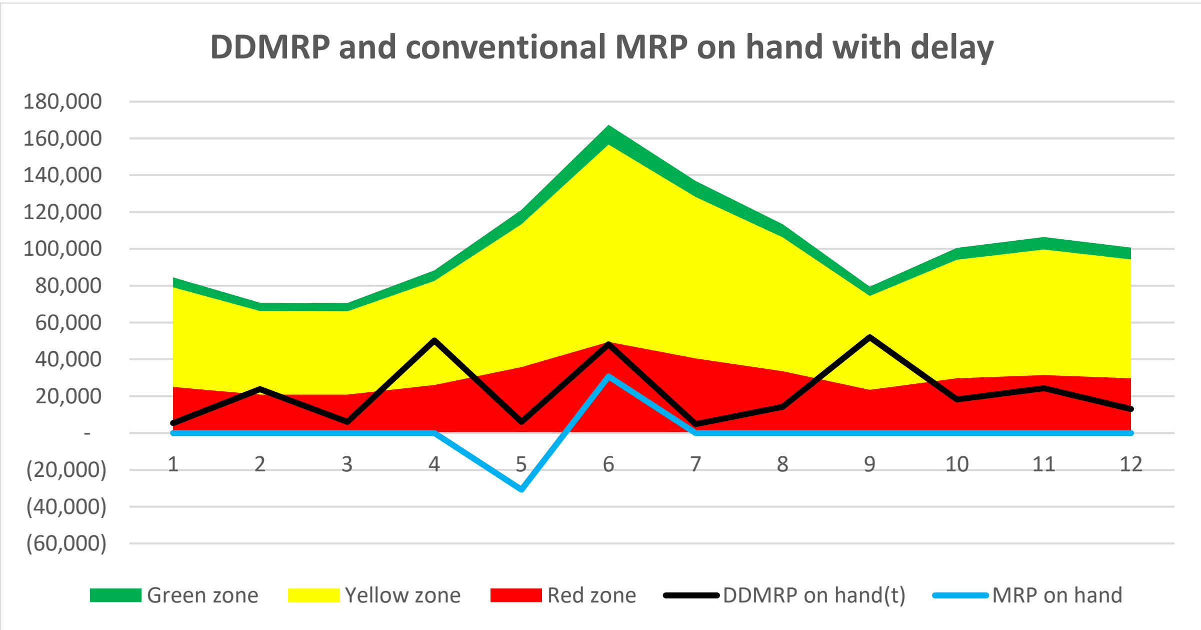


Figure 3. 14: Overseas long lead time items utilize DDMRP with a delay



The figure compares on hand status of long ordering lead time of the same oversea part with figure 3.13 While conventional MRP target zero inventory, DDMRP remains a buffer amount as the trend of demand. DDMRP drives a buffer inventory to supply to production even in situations of delay in May. The on-hand amount in May slumps amount the same as demand of the month at 30,765 pieces, while with MRP strategy, there is a shortage of the same amount at minus 30,765 pieces. In June, when the delayed order is delivered, the on-hand DDMRP continue will be recovered that amount of the delay, and the amount of inventory remains an appropriate amount at 48,266 pieces.

DDMRP with domestic single items

Progress scrutinizes DDMRP with domestic single items with the diversification of lead time and other characteristics of items and demand and lead time. Items either have a short lead time or long lead time, on-hand material will fluctuate as demand and preserve positive even in a disruption situation. While with the MRP approach there is replenishment inventory to serve. The longer the lead time, the higher proportion of yellow service levels.

Figure 3.15 illustrates the different buffers and on hand when utilizing DDMRP in normal ordering processes of an item with an ordering lead time of 1 month. From the figure we can see that, with ordering lead time is 1 month, threshold of reorder and amount equivalent with security inventory cushion. On-hand material has stronger oscillation than buffer levels but remains high on-hand material to supply for production. There are 3 periods of on-hand slumps to the threshold of red alert in January, August, and October.

Figure 3. 15: Domestic short lead time item utilizes DDMRP without delays

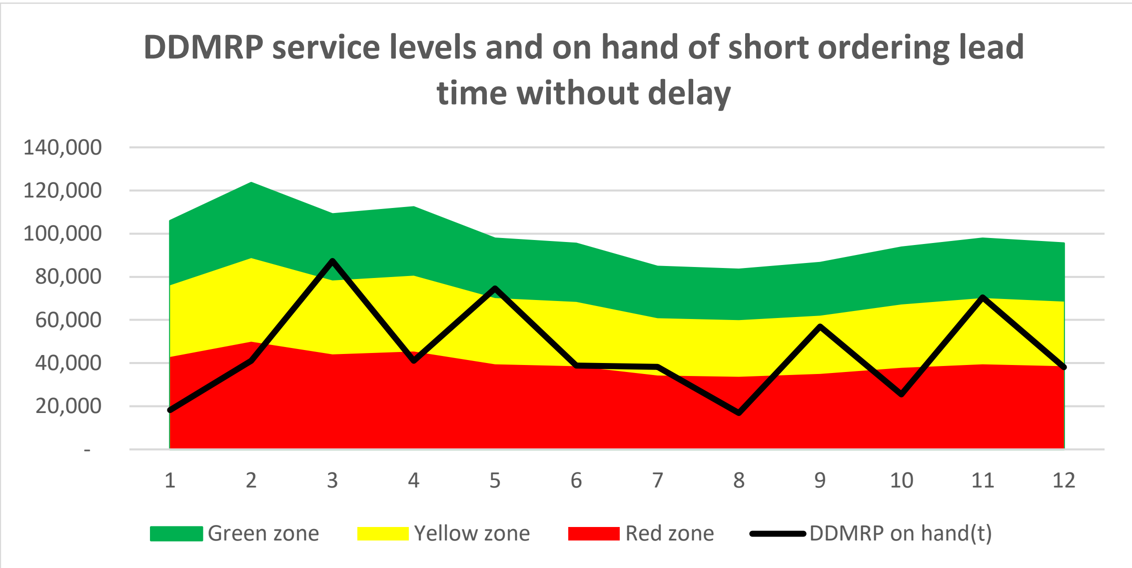
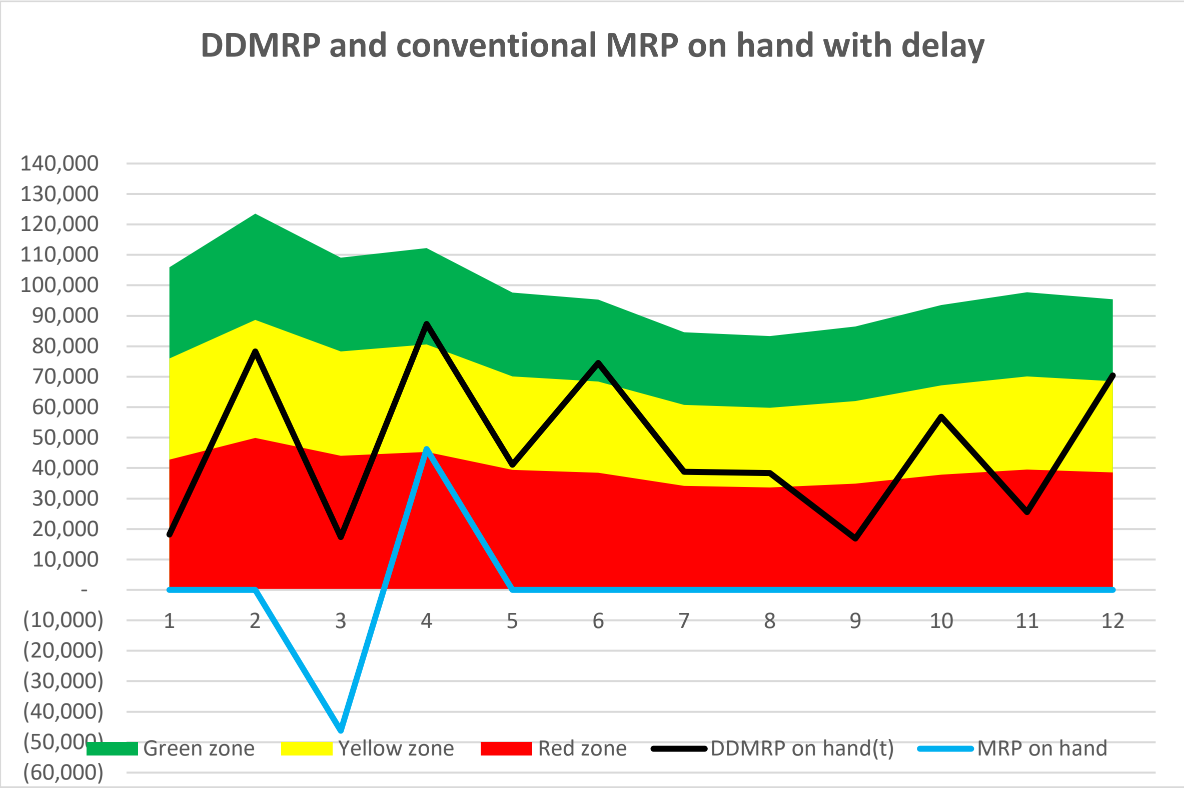


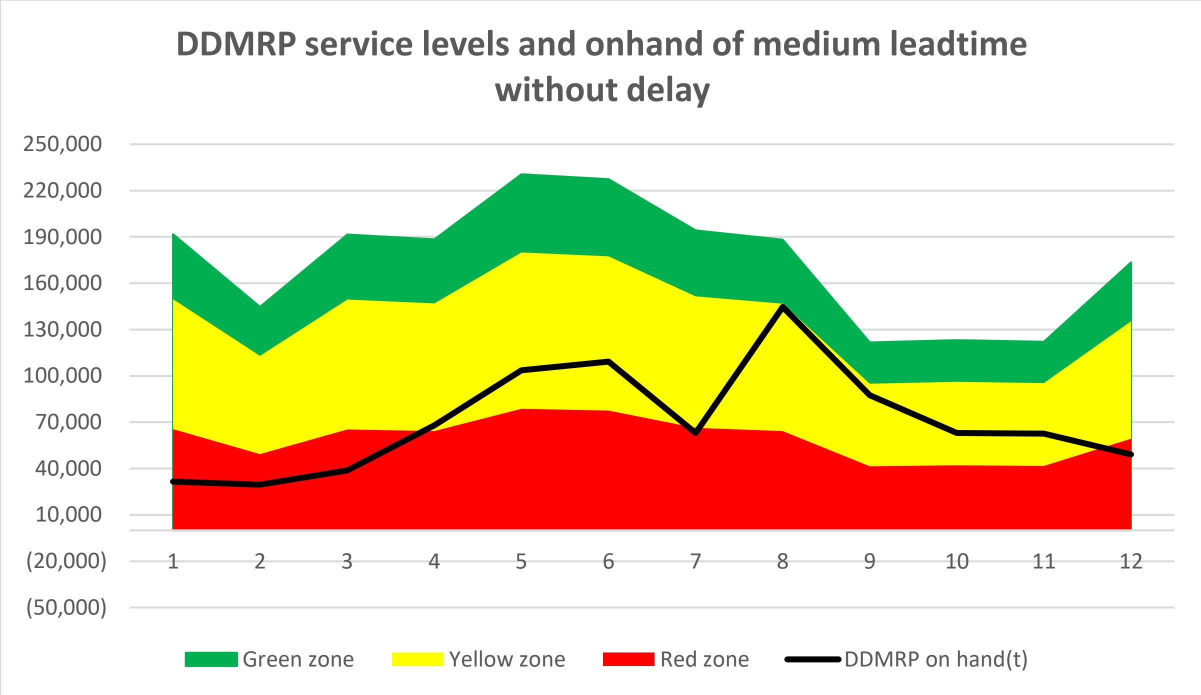
Figure 3. 16: Domestic short lead time items utilize DDMRP with a delay



Graph 3.16 compares on hand status of a single domestic item with an ordering lead time is 1 month when it has a delay in March 2021. With DDMRP the on-hand amount decreases a mount as same as the demand of March with 46,243 pieces, in April, inventory is an additional amount of the delay in March. On another approach with conventional MRP, in March, the delay leads to a lack of material for the production amount of 46,243 pieces. But in April inventory soars amount equals to the shortage in March. Other months with MRP and DDMRP toward as the methodology principles of balancing inventory and buffers.

The author continues to analyze the DDMRP approach with domestic single items, which have a medium ordering lead time of 2 months. Figures 3.17 and 3.18 indicate buffer positions of the item in normal ordering conditions and compare the state of on-hand material when there is a delay with two different approaches of DDMRP and conventional MRP.

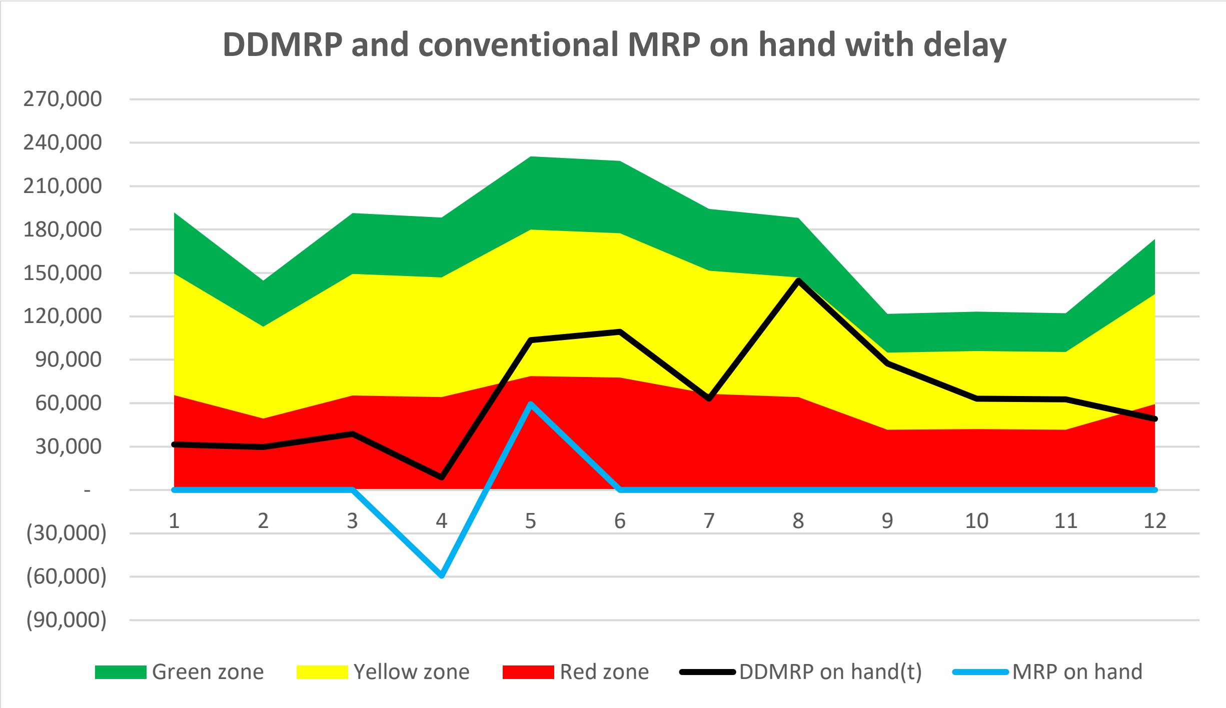
Figure 3. 17: Domestics medium lead time items utilize DDMRP without delays



With the higher risk of a longer lead time of 2 months, with DDMRP the planner can reorder at a higher yellow threshold in comparison with 1 month ordering lead time. From figure 3.4, it can be easy to see that amount of each order is relative more frequently and lower to avoid shortage. On-hand, material remains relatively high and picks highest in August at 144,626 pieces while other months shift as same as the trend of the demand.

Another perspective of on-hand status is when there is a delivery disruption in April, which is scratched in figure 3.17. In April both DDMRP and MRP on hand amounts are reduced amount exactly to the demand of that month, however with DDMRP, inventory decreases by 59,283 pieces but remains positive, while MRP inventory slumps under zero and lacks production supply of 59,283 pieces. After that, the delay delivered in May the inventory raises immediately with a large amount of material in the warehouse. With DDMRP inventory is remain highest in August and other months fluctuate as same as the trend of buffer zones, while the conventional MRP approach keeps the target of zero inventory.

Figure 3.18: On-hand status of a domestic item with medium ordering lead time when applying DDMRP and conventional MRP



Finally, figure 3.19 and figure 3.20 represent the position of buffer zones and on-hand status of a domestic item with a long ordering lead time of 3 months. The yellow threshold of reordering points remains highest in comparison with items with short and medium ordering lead time, while the amount of each order is small relative to green threshold. High inventory continues to apply to hedge the long lead time risk and varies with the variance of buffer zones. The o status of this item when applying DDMRP and conventional MRP when there is a delay keeps going on as the logic of short and medium ordering lead time items. This amount shows in figure 3.20 with an understock of material with the conventional MRP approach at minus 23,534 pieces in May and respectively inventory in DDMRP reduces that amount. In June, inventory is recovering the shortage amount in May and continues with the trend of the on-hand materials without any delay as in figure 3.19.

Figure 3. 19: Domestics long lead time items utilize DDMRP without delays

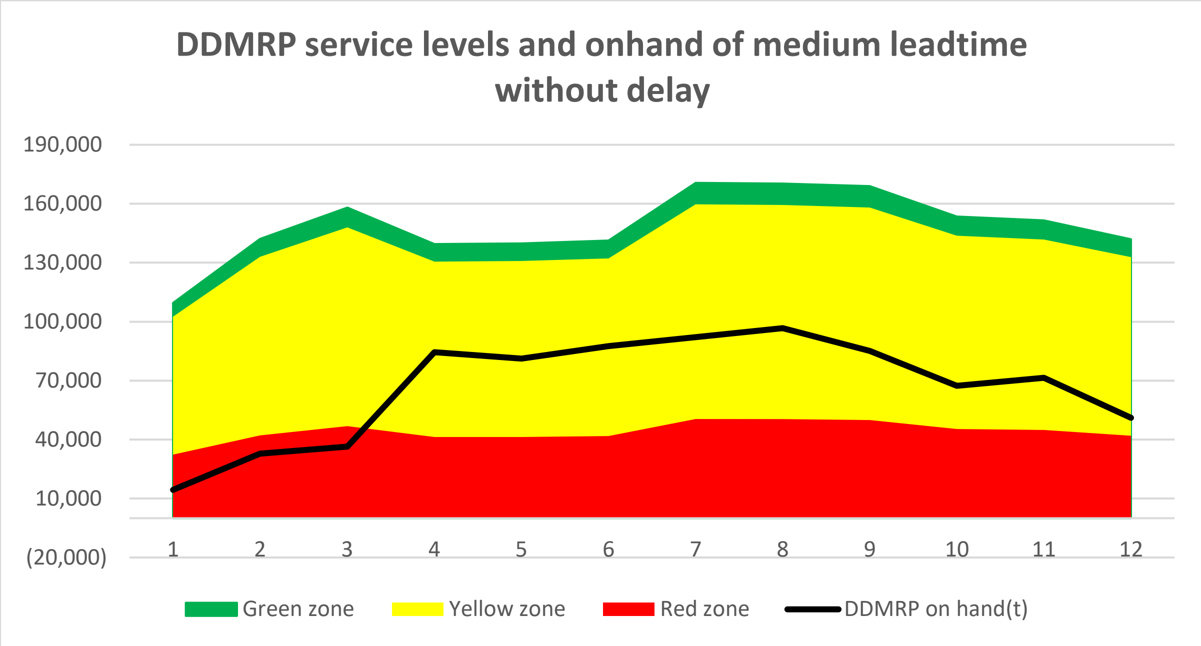
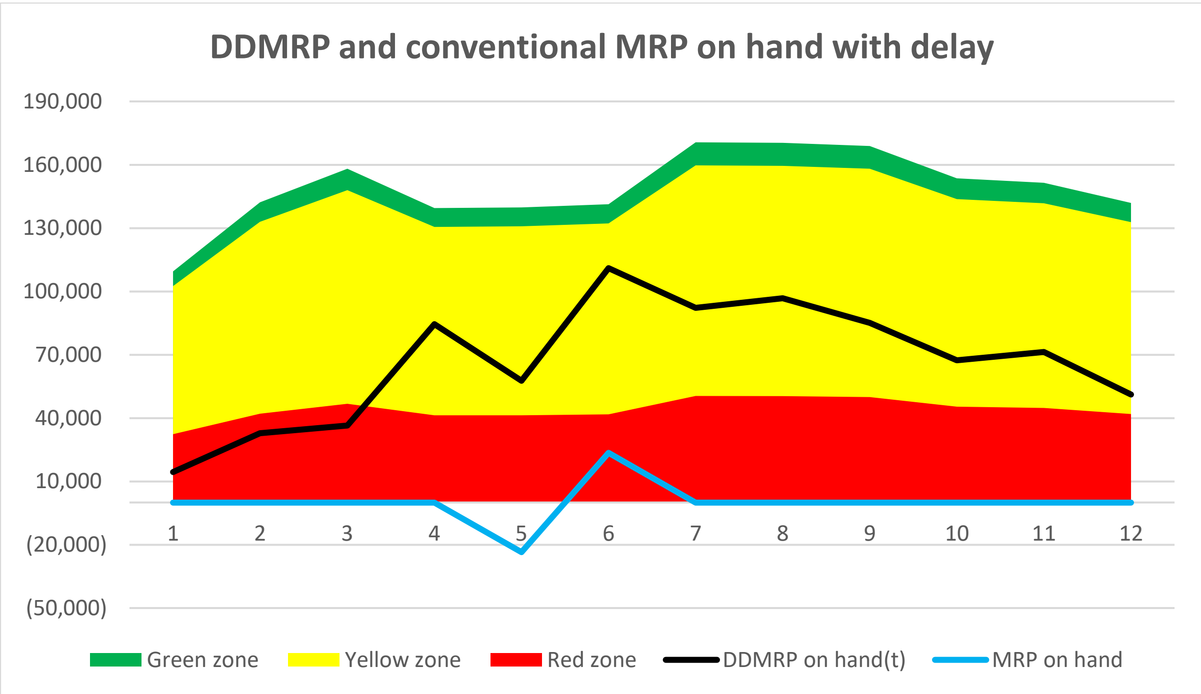


Figure 3. 20: On-hand status of a domestic item with long a ordering lead time when applying DDMRP and conventional MRP



In conclusion of DDMRP investigation with both single items overseas and domestic with different lead times and demand. As the developed model is applied by numerous international corporations, again experimented, and exanimated the applicable and appropriate implication in this case study. The viral mission of DDMRP and its buffers is to help the company define when and how to reorder easily to avoid a shortage of material to supply for production. Higher reordering lead time, higher risk of ordering production, and higher inventory must be prepared. The reordering is more often, and the amount of each order is lower as observed from the figures representing buffer zones above. As the result, with the DDMRP approach, the company will be ready for any delay or demanding adjustment.

3.2.3.2. DDMRP under circumspective scrutiny of green zone error

Under circumspective scrutiny of error for green zone we suppose a higher value for a_G with intermediate and long lead time as table below:

Lead time(month)	Month	α	β	a_G
Short	1	1.03	0.25	0.9
Intermediate	2	0.67	0.16	0.8
Long	3	0.42	0.1	0.7

Figures 3.21 to 3.24 below compare green zone services and on-hand DDMRP as the model developed and applied above and under the prudent circumstance with items that have an immediate and long lead times of 2 and 3 months. It is obvious to notice that when increasing the error coefficient of the green zone, both the green service level and on-hand materials will escalate whether it is a long lead time or intermediate lead time.

Figures 3.21 and 3.22 illustrate the threshold of the DDMRP green zone and an available inventory of items that have 2 months ordering lead time with the scenario of circumspective investigation. It is undoubted to observe the higher buffer and threshold of the green zone must be arranged to hedge the higher risk. Both green zone buffer and available material are fluctuated and rise higher in months of the fourth quarter of 2021, while in the beginning months of 2021 from January to March, the available inventory in the two scenarios has not significantly varied. A similar shifting trend with the green threshold when fluctuated and increased higher in the ending months in 2021 and lightly increased from March to May 2021.

Figure 3.21: Compare the green zone service of medium lead time items in two circumstances

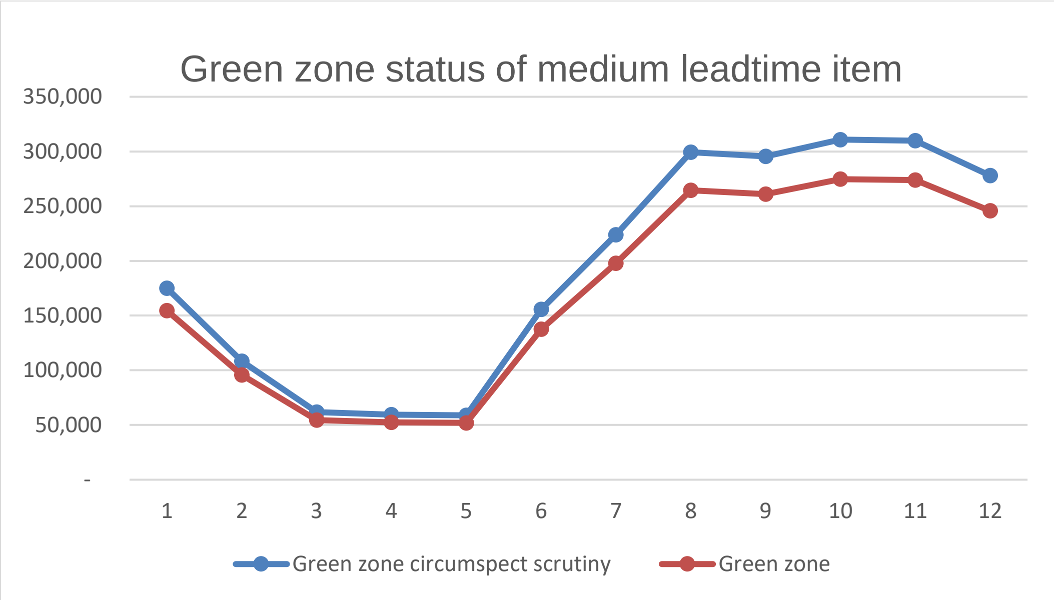
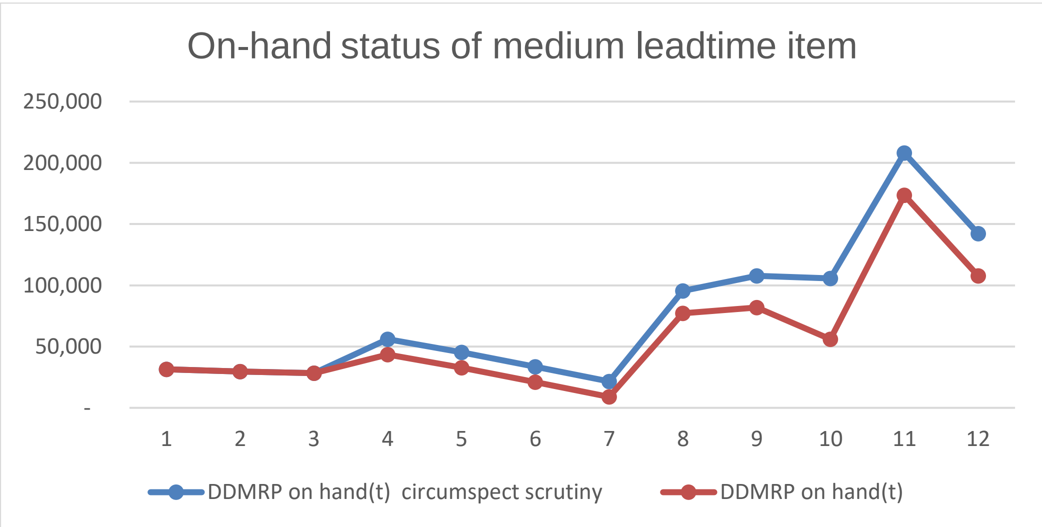


Figure 3.22: Compare the on-hand status of medium lead time items in two circumstances



In addition, figures 3.23 and 3.24 illustrate the threshold of the DDMRP green zone and on hand of the long lead time item which lasts 3 months ordering in a similar scenario of prudent investigation. A higher threshold with a parallel shifting trend with the normal scenario of the green zone is arranged to hedge the higher risk. On another hand, on hand material in prudent circumstances fluctuated sharply and had higher variation than the original. From August to September 2021, it increased socket, in contrast from September to November it slumped deeply. From April to August available material increased higher and parallel displacement with the normal. While in the normal circumstance in August and in November it increases slightly as green line in graph 3.24.

Figure 3.23: Compare the green zone service of long lead time item in two circumstances

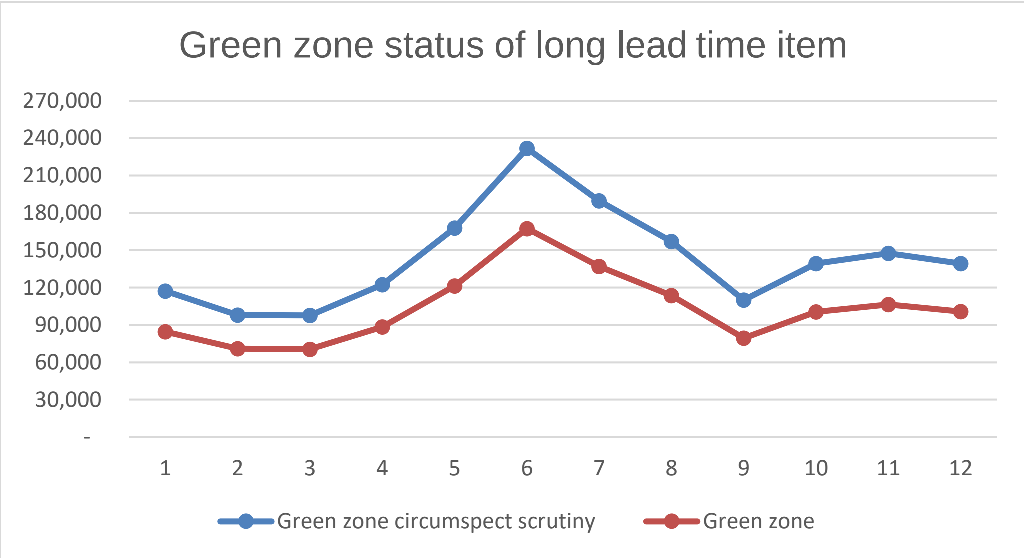
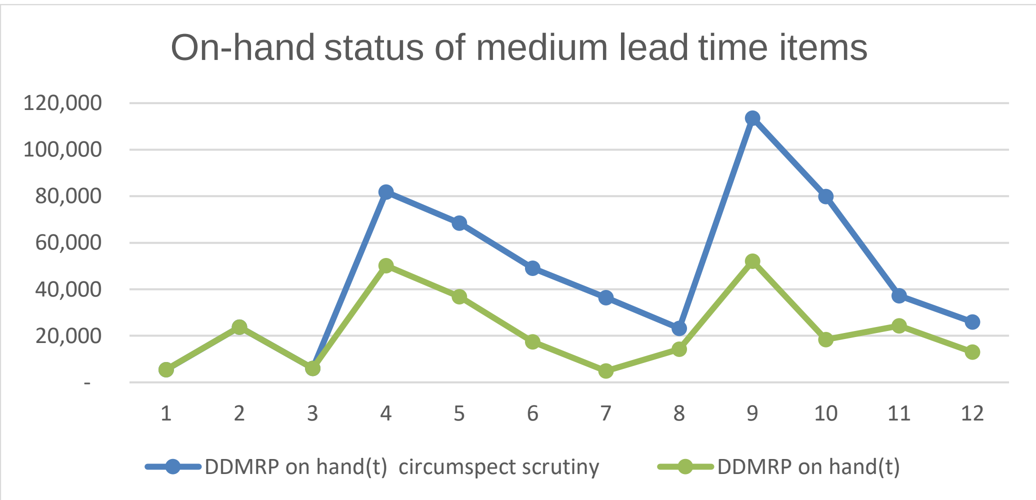


Figure 3.24: Compare the on-hand status of long lead time item in two circumstances



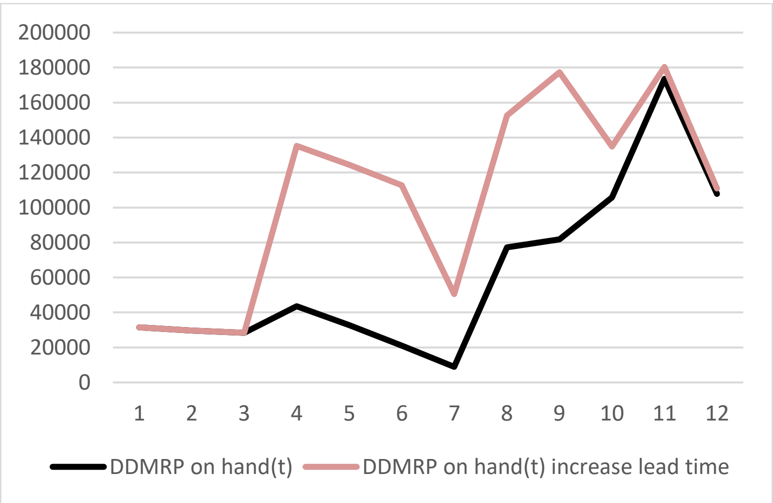
4.2.3.3. DDMRP under the scrutiny of higher order lead time

The company produces durable goods for this requirement, some items can have a specific architecture with longer lead time order as a strategy of made-for design. In this section, the researcher is going to explore the DDMRP on-hand status as an increased ordering lead time from 2 months to 6 months which is accounted as a medium lead time. The assumption is represented as follows:

Lead time(month)	Month	α	β	a_G
Short	1	1.03	0.25	0.9
Intermediate	6	0.67	0.16	0.8

Figure 3.25 indicates the status of on-hand items when increased lead time orders as requisites. Leadtime directly affects to service lever of each zone in DDMRP, as the linkage, any modification in lead time will direct ordering and inventory. The graphs certify the assumption as a longer lead time, higher inventory will remain to avoid deficiency. Each purchasing order lasts longer, and the higher probabilities of risk and consolidation together will create more impacts on available material. It is proved as a 3.25 line graph, at the beginning and ending periods, available inventory in two scenarios does not deviate too much but in the next periods, inventory fluctuates frequently as the red line.

Figure 3.25: On-hand status with the medium lead time



When the lead time increase from 2 to 6 months, the risk of delivery increases sharply, and the company must prepare extremely high inventory to hedge any ordering delay.

Corresponding with this, the firm has to charge for costly inventory strategy and small ratio of benefits or even they have to accept to produce without profit to remain customers' loyalty and company reputation.

In conclusion, the DDMRP approach proved to avoid shortage of material in any risks through three service zones. The risk factor helps decision-makers can adapt ordering strategies depending on the actual circumstances, the higher the risk factor and longer lead time, the higher on-hand material remains.

CHAPTER 4 CONCLUSION AND RECOMMENDATION

The target of this research is to investigate the production strategy of the company and its MRP approach with both advantages and drawbacks. Moreover, under scrutiny the appropriation of DDMRP to help the company match operation efficiency management in risk situations to maintain buffer inventory. In this section, we are going to summarize the main key values which are studied in this research.

The company is employing a complex hybrid production strategy with lot-for-lot materials ordering. In addition, the manufacturing activities are operated preceding instead of in the exact period of demand. This manufacturing is considered the hedging tactic of the company in an uncertain situation. All the mentioned tactics combined with their bias as their working experience resistant cause of traditional LEAN or just-in-time strategies which drives the company to shortage of material in production and services level. Furthermore, in the scenario of risks and uncertainty in operation and supply chain management, the company is interfacing the inefficient and diminishing profit. Innovation in manufacturing and management systems with an emphasis on product strategy, and materials planning are key components for any firm in the manufacturing sector.

The scrutiny of the company's MRP strategy with Heuristics and Exact methods proves the advantages of the company ordering strategy as lot-for-lot with some categories. However, this ordering strategy cannot employ for all single items as some categories should utilize hybrid ordering by merging demand of some continuous period as a cluster or combining both lot-for-lot and merge demand ordering. Furthermore, the conventional MRP strategy has not yet emphasized buffer material in ordering disruption, and it causes a shortage in production supply.

DDMRP as its principle to protect the smooth of services processes and guarantee inventory even if there are any order delays. Investigations in chapter 3 reconfirm the appropriation of the DDMRP approach to hedge the shortage inventory in a complicated and uncertain supply chain circumstance.

This study contributes a reference for the company to revise and flourish the processes of innovation operation management and focus on material requirements planning. In application, the decision-makers should distinguish into clusters of single items as precise lead time coefficient and the yield of qualified items can be considered as a component of the risk factor. Moreover, this study has not yet evaluated DDMRP efficiency from an inventory cost perspective. For further study with this case study can continue to propose and get deeper into the perspective of cost management.

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Appendix A: Detail 2021 MRP

Details conventional MRP of both overseas and domestic items in 2021 with delay orders are highlighted in yellow, delayed periods and late delivered in orange.

Item I	**Period**	**T-I**		**Jan-21**	**Feb-21**	**Mar-21**	**Apr-21**	**May-21**	**Jun-21**	**Jul-21**	**Aug-21**	**Sep-21**	**Oct-21**	**Nov-21**	**Dec-21**
	Demand			3,101	3,438	4,319	4,211	13,526	13,526	3,532	3,101	11,472	13,368	15,458	15,458
LeadTime: 1 month	On hand	57		-	-	-	(4,211)	4,211	-	-	-	-	-	-	-
Unit cost= $42.50	Net requirements			3,044	3,438	4,319	4,211	17,737	9,315	3,532	3,101	11,472	13,368	15,458	15,458
On hand: 57	Planned order receipts			3,044	3,438	4,319	-	21,948	9,315	3,532	3,101	11,472	13,368	15,458	15,458
	Planned order releases			3,044	3,438	4,319	4,211	17,737	9,315	3,532	3,101	11,472	13,368	15,458	15,458
	Order cost (USD)			**129,370**	**146,115**	**183,558**	**-**	**932,790**	**395,888**	**150,110**	**131,793**	**487,560**	**568,140**	**656,965**	**656,965**

Item II	**Period**	**T-I**		**Jan-21**	**Feb-21**	**Mar-21**	**Apr-21**	**May-21**	**Jun-21**	**Jul-21**	**Aug-21**	**Sep-21**	**Oct-21**	**Nov-21**	**Dec-21**
	Demand			18,824	13,480	10,816	11,688	12,088	10,472	68,104	51,704	54,456	65,848	60,640	53,888
LeadTime: 2 months	On hand	143		-	-	(10,816)	10,816	-	-	-	-	-	-	-	-
Unit cost= $ 15.95	Net requirements			18,681	13,480	10,816	22,504	1,272	10,472	68,104	51,704	54,456	65,848	60,640	53,888
On hand: 143	Planned order receipts			18,681	13,480	-	33,320	1,272	10,472	68,104	51,704	54,456	65,848	60,640	53,888
	Planned order releases	18,68 1		13,480	10,816	22,504	1,272	10,472	68,104	51,704	54,456	65,848	60,640	53,888	77,225
	Order cost (USD)			**297,962**	**215,006**	**-**	**531,454**	**20,288**	**167,028**	**1,086,259**	**824,679**	**868,573**	**1,050,276**	**967,208**	**859,514**

Item III	Period	T-(l+1)	T-l	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
	Demand			3,347	2,395	2,624	3,174	9,765	11,720	2,722	2,276	8,671	10,983	11,766	12,472
LeadTime: 3 months	On hand	84		-	-	-	-	(9,765)	9,765	-	-	-	-	-	-
Unit cost= $35.70	Net requirements			3,263	2,395	2,624	3,174	9,765	21,485	(7,043)	2,276	8,671	10,983	11,766	12,472
On hand: 84	Planned order receipts			3,263	2,395	2,624	3,174	-	31,250	(7,043)	2,276	8,671	10,983	11,766	12,472
	Planned order releases	3,263	2,395	2,624	3,174	9,765	21,485	(7,043)	2,276	8,671	10,983	11,766	12,472		
	Order cost (USD)			**116,489**	**85,501**	**93,676**	**113,311**	**-**	**1,115,625**	**(251,43)**	**81,253**	**309,554**	**392,093**	**420,046**	**445,250**

Item IV	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
	Demand			**28,492**	**48,294**	**18,534**	**59,283**	**46,235**	**46,374**	**57,231**	**24,352**	**42,356**	**13,425**	**25,352**	**41,632**
LeadTime: 2 months	On hand	154		-	-	-	(59,283)	59,283	-	-	-	-	-	-	-
Unit cost= $42.40	Net requirements			28,492	48,294	18,534	59,283	105,518	(12,909)	57,231	24,352	42,356	13,425	25,352	41,632
On hand: 154	Planned order receipts			28,492	48,294	18,534	-	164,801	(12,909)	57,231	24,352	42,356	13,425	25,352	41,632
	Planned order releases		28,492	48,294	18,534	59,283	105,518	(12,909)	57,231	24,352	42,356	13,425	25,352	41,632	247,212
	Order cost (USD)			**1,208,061**	**2,047,666**	**785,842**	**-**	**6,987,562**	**(547,342)**	**2,426,594**	**1,032,525**	**1,795,894**	**569,220**	**1,074,925**	**1,765,197**

Item V	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
LeadTime: 1 month Unit cost= $36.30 On hand: 173	**Demand**			**37,285**	**32,742**	**46,243**	**23,654**	**35,745**	**32,534**	**21,453**	**25,673**	**31,345**	**24,351**	**32,353**	**35,246**
	On hand	173		-	-	(46,243)	46,243	-	-	-	-	-	-	-	-
	Net requirements			37,112	32,742	46,243	23,654	81,988	(13,709)	21,453	25,673	31,345	24,351	32,353	35,246
	Planned order receipts			37,112	32,742	-	69,897	81,988	(13,709)	21,453	25,673	31,345	24,351	32,353	35,246
	Planned order releases			37,112	32,742	46,243	23,654	81,988	(13,709)	21,453	25,673	31,345	24,351	32,353	35,246
	Order cost (USD)			**1,347,166**	**1,188,535**	**-**	**2,537,261**	**2,976,164**	**(497,637)**	**778,744**	**931,930**	**1,137,824**	**883,941**	**1,174,414**	**1,279,430**

Item VI	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
LeadTime: 3 months Unit cost= $57.30 On hand: 259	**Demand**			**13,243**	**35,423**	**42,334**	**23,453**	**23,534**	**42,534**	**24,354**	**42,353**	**42,353**	**23,432**	**32,542**	**41,034**
	On hand	259		-	-	-	-	(23,534)	23,534	-	-	-	-	-	-
	Net requirements			12,984	35,423	42,334	23,453	23,534	42,534	47,888	18,819	42,353	23,432	32,542	41,034
	Planned order receipts			12,984	35,423	42,334	23,453	-	66,068	47,888	18,819	42,353	23,432	32,542	41,034
	Planned order releases	12,984	35,423	42,334	23,453	23,534	42,534	47,888	18,819	42,353	23,432	32,542	41,034	180,262	206,068
	Order cost (USD)			**743,983**	**2,029,738**	**2,425,738**	**1,343,857**	**-**	**3,785,696**	**2,743,982**	**1,078,329**	**2,426,827**	**1,342,654**	**1,864,657**	**2,351,248**

Item VII	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
	Demand			**88,320**	**96,768**	**114,544**	**110,364**	**113,792**	**158,144**	**117,376**	**69,594**	**149,504**	**94,500**	**63,000**	**112,432**
LeadTime: 3 moths	On hand	254		-	(96,768)	96,768	-	-	-	-	-	-	-	-	-
Unit cost= $19.75	Net requirements			88,066	96,768	211,312	13,596	113,792	158,144	117,376	69,594	149,504	94,500	63,000	112,432
On hand: 254	Planned order receipts			88,066	-	308,080	13,596	113,792	158,144	117,376	69,594	149,504	94,500	63,000	112,432
	Planned order releases	88,066	96,768	211,312	13,596	113,792	158,144	117,376	69,594	149,504	94,500	63,000	112,432		
	Order cost (USD)			**1,739,304**	**-**	**6,084,580**	**268,521**	**2,247,392**	**3,123,344**	**2,318,176**	**1,374,482**	**2,952,704**	**1,866,375**	**1,244,250**	**2,220,532**

Item VIII	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
	Demand			**33,376**	**22,080**	**24,192**	**28,448**	**39,536**	**29,344**	**24,384**	**33,888**	**25,152**	**13,536**	**6,750**	**4,500**
LeadTime: 2 months	On hand	162		-	-	(24,192)	24,192	-	-	-	-	-	-	-	-
Unit cost= $35.87	Net requirements			33,214	22,080	24,192	52,640	15,344	29,344	24,384	33,888	25,152	13,536	6,750	4,500
On hand:162	Planned order receipts			33,214	22,080		76,832	15,344	29,344	24,384	33,888	25,152	13,536	6,750	4,500
	Planned order releases	33,214	22,080	22,080	24,192	52,640	15,344	29,344	24,384	33,888	25,152	13,536	6,750	4,500	176,814
	Order cost (USD)			**1,191,386**	**792,010**	**-**	**2,755,964**	**550,389**	**1,052,569**	**874,654**	**1,215,563**	**902,202**	**485,536**	**242,123**	**161,415**

Item IX	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
	Demand			**4,064**	**5,648**	**4,192**	**4,971**	**4,064**	**5,648**	**4,192**	**4,971**	**3,350**	**8,636**	**7,452**	**5,274**
LeadTime: 2 months	On hand	96		(3,968)	3,968	-	-	-	-	-	-	-	-	-	-
Unit cost= $52.40	Net requirements			3,968	9,616	224	4,971	4,064	5,648	4,192	4,971	3,350	8,636	7,452	5,274
On hand: 96	Planned order receipts			-	13,584	224	4,971	4,064	5,648	4,192	4,971	3,350	8,636	7,452	5,274
	Planned order releases	3,968	9,616	9,616	224	4,971	4,064	5,648	4,192	4,971	3,350	8,636	7,452	5,274	28,491
	Order cost (USD)			**-**	**711,802**	**11,738**	**260,480**	**212,954**	**295,955**	**219,661**	**260,480**	**175,540**	**452,526**	**390,485**	**276,358**

Item X	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
	Demand			**40,568**	**37,458**	**42,764**	**27,448**	**37,589**	**42,647**	**49,744**	**57,836**	**26,145**	**23,815**	**47,256**	**48,794**
LeadTime: 1 month	On hand	287		-	-	-	-	-	(42,647)	42,647	-	-	-	-	-
Unit cost= $31.54	Net requirements			40,281	37,458	42,764	27,448	37,589	42,647	92,391	15,189	26,145	23,815	47,256	48,794
On hand: 287	Planned order receipts			40,281	37,458	42,764	27,448	37,589	-	135,038	15,189	26,145	23,815	47,256	48,794
	Planned order releases			40,281	37,458	42,764	27,448	37,589	42,647	92,391	15,189	26,145	23,815	47,256	48,794
	Order cost (USD)			**1,270,463**	**1,181,425**	**1,348,777**	**865,710**	**1,185,557**	**-**	**4,259,099**	**479,061**	**824,613**	**751,125**	**1,490,454**	**1,538,963**

Item XI	**Period**	**T-l**		**Jan-21**	**Feb-21**	**Mar-21**	**Apr-21**	**May-21**	**Jun-21**	**Jul-21**	**Aug-21**	**Sep-21**	**Oct-21**	**Nov-21**	**Dec-21**
	Demand			**24,536**	**19,735**	**20,465**	**25,143**	**37,345**	**28,795**	**30,578**	**25,637**	**19,835**	**18,794**	**25,793**	**28,674**
LeadTime: 3 months	On hand	163		-	-	-	(25,143)	25,143	-	-	-	-	-	-	-
Unit cost= $3.57	Net requirements			24,373	19,735	20,465	25,143	62,488	3,652	30,578	25,637	19,835	18,794	25,793	28,674
On hand: 163	Planned order receipts			24,373	19,735	20,465	-	87,631	3,652	30,578	25,637	19,835	18,794	25,793	28,674
	Planned order releases	24,373	19,735	20,465	25,143	62,488	3,652	30,578	25,637	19,835	18,794	25,793	28,674		
	Order cost (USD)			**87,012**	**70,454**	**73,060**	**-**	**312,843**	**13,038**	**109,163**	**91,524**	**70,811**	**67,095**	**92,081**	**102,366**

Item XII	**Period**	**T-l**		**Jan-21**	**Feb-21**	**Mar-21**	**Apr-21**	**May-21**	**Jun-21**	**Jul-21**	**Aug-21**	**Sep-21**	**Oct-21**	**Nov-21**	**Dec-21**
	Demand			**7,846**	**9,567**	**7,456**	**6,748**	**7,894**	**8,694**	**9,856**	**3,785**	**6,497**	**3,679**	**9,748**	**8,579**
LeadTime: 1 month	On hand	304		-	(9,567)	9,567	-	-	-	-	-	-	-	-	-
Unit cost= $53.70	Net requirements			7,542	9,567	17,023	(2,819)	7,894	8,694	9,856	3,785	6,497	3,679	9,748	8,579
On hand: 304	Planned order receipts			7,542	-	26,590	(2,819)	7,894	8,694	9,856	3,785	6,497	3,679	9,748	8,579
	Planned order releases			7,542	9,567	17,023	(2,819)	7,894	8,694	9,856	3,785	6,497	3,679	9,748	8,579
	Order cost (USD)			**405,005**	**-**	**1,427,883**	**(151,380)**	**423,908**	**466,868**	**529,267**	**203,255**	**348,889**	**197,562**	**523,468**	**460,692**

Item XIII	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
	Demand			**8,454**	**6,734**	**5,245**	**9,674**	**8,465**	**8,945**	**6,245**	**9,456**	**8,345**	**8,645**	**9,567**	**9,785**
LeadTime: 3 months	On hand	95		(8,359)	8,359	-	-	-	-	-	-	-	-	-	-
Unit cost= $52.50	Net requirements			8,359	6,734	13,604	1,315	8,465	8,945	6,245	9,456	8,345	8,645	9,567	9,785
On hand: 95	Planned order receipts			-	15,093	13,604	1,315	8,465	8,945	6,245	9,456	8,345	8,645	9,567	9,785
	Planned order releases	8,359	6,734	13,604	1,315	8,465	8,945	6,245	9,456	8,345	8,645	9,567	9,785	47,422	52,043
	Order cost (USD)			**-**	**792,383**	**714,210**	**69,038**	**444,413**	**469,613**	**327,863**	**496,440**	**438,113**	**453,863**	**502,268**	**513,713**

Item XIV	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
	Demand			**6,745**	**8,756**	**7,956**	**8,564**	**9,854**	**7,896**	**5,432**	**8,756**	**7,896**	**7,456**	**9,756**	**7,545**
LeadTime: 2 months	On hand	164		-	-	-	-	-	(7,896)	7,896	-	-	-	-	-
Unit cost= $43.60	Net requirements			6,745	8,756	7,956	8,564	9,854	7,896	13,328	860	7,896	7,456	9,756	7,545
On hand: 164	Planned order receipts			6,745	8,756	7,956	8,564	9,854	-	21,224	860	7,896	7,456	9,756	7,545
	Planned order releases		6,745	8,756	7,956	8,564	9,854	7,896	13,328	860	7,896	7,456	9,756	7,545	49,771
	Order cost (USD)			**294,082**	**381,762**	**346,882**	**373,390**	**429,634**	**-**	**925,366**	**37,496**	**344,266**	**325,082**	**425,362**	**328,962**

Item XV	Period	T-l		Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
	Demand			**32,412**	**35,423**	**12,354**	**56,354**	**56,735**	**45,634**	**64,532**	**46,753**	**42,534**	**23,456**	**34,523**	**35,463**
LeadTime: 1 month	On hand	247		-	(35,423)	35,423	-	-	-	-	-	-	-	-	-
Unit cost= $35.60	Net requirements			32,165	35,423	12,354	91,777	21,312	45,634	64,532	46,753	42,534	23,456	34,523	35,463
On hand: 247	Planned order receipts			32,165	-	47,777	91,777	21,312	45,634	64,532	46,753	42,534	23,456	34,523	35,463
	Planned order releases			32,165	35,423	12,354	91,777	21,312	45,634	64,532	46,753	42,534	23,456	34,523	35,463
	Order cost (USD)			**1,145,074**	**-**	**1,700,861**	**3,267,261**	**758,707**	**1,624,570**	**2,297,339**	**1,664,407**	**1,514,210**	**835,034**	**1,229,019**	**1,262,483**

Appendix B: Heuristic Silver Meal and Least Unit Cost analysis with both domestic and overseas items

These items have diversified ordering lead time from 1, 2, and 3 months; different costs and demands as in table" Analysis data". Summary from these analysis, ordering lot- for-lot is the optimal strategy to these items.

Analysis data

Leadtime	3	2	2	3	2	1	1	3	1
cost	$ 19.75	$ 35.87	$ 52.40	$ 52.50	$ 43.60	$ 35.60	$ 31.54	$ 3.57	$ 53.70
K	$ 1,002.52	$ 1,002.52	$ 823.52	$ 87.00	$ 150.00	$ 77.00	$ 905.52	$ 823.52	$ 973.52
h	$ 3.10	$ 2.25	$ 3.26	$ 0.32	$ 0.25	$ 0.35	$ 1.52	$ 3.29	$ 1.20
Jan	88,320	33,376	4,064	8,454	6,745	32,412	40,568	24,536	7,846
Feb	96,768	22,080		6,734	8,756	35,423	37,458	19,735	9,567
Mar	114,544	24,192	4,192	5,245	7,956	12,354	42,764	20,465	7,456
Apr	110,364	28,448	4,971	9,674	8,564	56,354	27,448	25,143	6,748
May	113,792	39,536	4,064	8,465	9,854	56,735	37,589	37,345	7,894
Jun	158,144	29,344	5,648	8,945	7,896	45,634	42,647	28,795	8,694

Silver meal

G(1)=	$ 1,003	$ 1,003	$ 824	$ 87	$ 150	$ 77	$ 906	$ 824	$ 974
G(2)=	$ 150,492	$ 25,341	$ 9,618	$ 1,121	$ 1,170	$ 6,238	$ 28,921	$ 32,876	$ 6,227
G(3)=	$ 337,052	$ 53,182	$ 15,523	$ 1,866	$ 2,106	$ 7,041	$ 62,615	$ 66,804	$ 10,116
G(4)=	$ 509,385	$ 87,893	$ 23,796	$ 3,721	$ 3,185	$ 20,074	$ 78,252	$ 112,143	$ 13,660
G(5)=	$ 689,712	$ 141,479	$ 29,636	$ 5,144	$ 4,519	$ 31,945	$ 108,310	$ 188,007	$ 18,506
G(6)=	$ 983,299	$ 172,919	$ 40,040	$ 6,672	$ 5,411	$ 39,931	$ 144,278	$ 235,618	$ 24,116
Local min at:	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

G(1)=	$ 1,003	$ 1,003	$ 824	$ 87	$ 150	$ 77	$ 906	$ 824	$ 974
G(2)=	$ 178,044	$ 27,717	$ 7,245	$ 883	$ 1,070	$ 2,200	$ 32,953	$ 34,077	$ 4,960
G(3)=	$ 61,150	$ 61,150	$ 61,150	$ 2,652	$ 2,140	$ 14,616	$ 77,865	$ 77,865	$ 77,865
G(4)=	$ 112,580	$ 112,580	$ 112,580	$ 4,021	$ 3,453	$ 25,855	$ 150,547	$ 150,547	$ 150,547
G(5)=	$ 142,883	$ 142,883	$ 142,883	$ 5,507	$ 4,342	$ 33,462	$ 196,226	$ 196,226	$ 196,226
Local min at:	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

G(1)=	$ 1,003	$ 1,003	$ 824	$ 87	$ 150	$ 77	$ 906	$ 824	$ 974
G(2)=	$ 171,565	$ 32,505	$ 8,514	$ 1,591	$ 1,146	$ 9,900	$ 21,313	$ 41,772	$ 4,536
G(3)=	$ 349,547	$ 80,974	$ 14,509	$ 2,867	$ 2,406	$ 19,838	$ 52,299	$ 109,758	$ 9,339
G(4)=	$ 629,845	$ 110,249	$ 24,691	$ 4,297	$ 3,285	$ 26,858	$ 87,842	$ 153,370	$ 14,829
Local min at:	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

G(1)=	$ 1,003	$ 1,003	$ 824	$ 87	$ 150	$ 77	$ 906	$ 824	$ 974
G(2)=	$ 245,624	$ 33,513	$ 9,618	$ 1,475	$ 1,062	$ 8,024	$ 32,864	$ 47,780	$ 5,703
G(3)=	$ 444,750	$ 74,002	$ 16,966	$ 2,840	$ 2,187	$ 17,293	$ 62,563	$ 104,387	$ 10,437
Local min at:	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

G(1)=	$ 1,003	$ 1,003	$ 824	$ 87	$ 150	$ 77	$ 906	$ 824	$ 974
G(2)=	$ 245,624	$ 33,513	$ 9,618	$ 1,475	$ 1,062	$ 8,024	$ 32,864	$ 47,780	$ 5,703
Local min at:	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

Least unit cost

G(1)=	0.0114	0.0300	0.2026	0.0103	0.0222	0.0024	0.0223	0.0336	0.1241
G(2)=	1.6262	0.9139	1.9806	0.1476	0.1509	0.1839	0.7413	1.4852	0.7152
G(3)=	3.3747	2.0031	3.3492	0.2740	0.2693	0.2634	1.5551	3.0958	1.2203
G(4)=	4.9697	3.2524	5.0429	0.4944	0.3979	0.5881	2.1115	4.9909	1.7282
G(5)=	6.5839	4.7916	6.4597	0.6668	0.5396	0.8264	2.9143	7.3888	2.3419
G(6)=	8.6516	5.8625	8.4039	0.8425	0.6523	1.0028	3.7889	9.0611	3.0017
Local min at:	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

G(1)=	0.0104	0.0454	0.1458	0.0129	0.0171	0.0022	0.0242	0.0417	0.1018
G(2)=	1.6851	1.1980	1.4725	0.1474	0.1280	0.0921	0.8216	1.6954	0.5828
G(3)=	3.2341	2.4552	3.1666	0.3675	0.2540	0.4211	1.3871	3.5749	1.0986
G(4)=	4.8192	3.9413	4.5905	0.5340	0.3932	0.6429	2.2082	5.8643	1.7222
G(5)=	6.8388	4.9750	6.5366	0.7048	0.5045	0.8102	3.0869	7.4620	2.3852
Local min at:	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

G(1)=	0.0088	0.0414	0.1965	0.0166	0.0189	0.0062	0.0212	0.0402	0.1306
G(2)=	1.5257	1.2350	1.8585	0.2133	0.1387	0.2882	0.6071	1.8318	0.6386
G(3)=	3.0655	2.7235	3.2037	1.0961	0.9018	1.1481	1.8933	3.7196	1.7569
G(4)=	8.1708	5.8790	8.4925	0.8516	0.6334	0.9780	3.8555	8.7799	3.1263
Local min at:	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

G(1)=	0.0091	0.0352	0.1657	0.0090	0.0175	0.0014	0.0330	0.0328	0.1443
G(2)=	1.5782	1.3232	1.5575	0.1541	0.1419	0.1763	0.8924	1.9794	0.7134
G(3)=	3.4901	2.2810	3.4664	0.3146	0.2494	0.3268	1.7429	3.4306	1.3418
Local min at:	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

G(1)=	0.0088	0.0254	0.2026	0.0103	0.0152	0.0014	0.0241	0.0221	0.1233
G(2)=	1.8065	0.9731	1.9806	0.1694	0.1197	0.1568	0.8192	1.4448	0.6876
Local min at:	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1	j0=1

Appendix C: Wagner Within the analysis

Analysis data: Items' data which is utilized to analyze with Exact method (Wagner Within)

Item		A	B	C	D	E	F	G	H	I
Unit cost		$ 19.75	$ 35.87	$ 52.40	$ 52.50	$ 43.60	$ 35.60	$ 31.54	$ 3.57	$ 53.70
Number of periods	T=	6	6	6	6	6	6	6	6	6
Ordering cost (fixed)	K=	$ 1,002.52	$ 1,002.52	$ 823.52	$ 87.00	$ 150.00	$ 77.00	$ 905.52	$ 823.52	$ 973.52
Holding cost (fixed)	h=	$ 3.10	$ 2.25	$ 3.26	$ 0.32	$ 0.25	$ 0.35	$ 1.52	$ 3.29	$ 1.20
January	r1=	88,320	33,376	4,064	8,454	6,745	32,412	40,568	24,536	7,846
February	r2=	96,768	22,080	5,648	6,734	8,756	35,423	37,458	19,735	9,567
March	r3=	114,544	24,192	4,192	5,245	7,956	12,354	42,764	20,465	7,456
April	r4=	110,364	28,448	4,971	9,674	8,564	56,354	27,448	25,143	6,748
May	r5=	113,792	39,536	4,064	8,465	9,854	56,735	37,589	37,345	7,894
June	r6=	158,144	29,344	5,648	8,945	7,896	45,634	42,647	28,795	8,694

Analysis results:

Wagner Within analysis results as above data with diversify ordering patterns and optimal costs. Each item has their own optimal ordering strategy.

Item A

f(1)	10,702,581
f(2)	8,957,258
f(3)	7,045,088
f(4)	4,781,841
f(5)	3,125,349
f(6)	1,003
f(7)	-

Matrix for partial costs: cij + f(j)

period	1	2	3	4	5	6
	10,702,581	11,001,559	11,710,729	13,260,311	13,794,378	19,367,951
		8,957,258	9,311,342	10,518,796	10,700,107	15,783,434
			7,045,088	7,910,413	7,738,969	12,332,050
				5,306,041	4,781,841	8,884,676
					3,125,349	5,861,985
						1,003
						-

Total Cost **10,702,581**

Optimal ordering strategy: at 1 order for January, at 2 orders for February, at 3 orders for March and April, at 5 orders for May and at 6 orders for June.

Item B

f(1)	4,935,988
f(2)	3,737,788
f(3)	2,944,776
f(4)	2,076,007
f(5)	1,054,574
f(6)	1,003
f(7)	-

Matrix for partial costs: cij + f(j)

period	1	2	3	4	5	6
	4,935,988	4,984,665	5,092,527	5,283,548	6,003,957	7,385,644
		3,737,788	3,791,218	3,918,231	4,549,684	5,865,347
			2,944,776	3,007,782	3,550,278	4,799,917
				2,076,007	2,529,547	3,713,162
					1,054,574	2,537,752
						1,003
						-

Total Cost **4,935,988**

Optimal ordering strategy: Lot- for- lot ordering strategy.

Item C

f(1)	1,219,370
f(2)	1,005,593
f(3)	708,814
f(4)	488,330
f(5)	297,602
f(6)	824
f(7)	-

Total Cost **1,219,370**

Matrix for partial costs: cij + f(j)

period	1	2	3	4	5	6
	1,219,370	1,236,959	1,263,467	1,381,836	1,351,006	1,738,200
		1,005,593	1,018,435	1,120,599	1,076,520	1,445,301
			708,814	794,772	737,445	1,087,814
				558,906	488,330	820,286
					297,602	528,145
						824
						-

Optimal ordering strategy: at 1 orders for January, February, and March, at 4 orders for April and May, at 6 orders for June.

Item D

f(1)	2,028,174
f(2)	1,584,252
f(3)	1,230,630
f(4)	955,180
f(5)	469,787
f(6)	87
f(7)	-

Total Cost: **2,028,174**

Matrix for partial costs: cij + f(j)

period	1	2	3	4	5	6
	2,028,174	2,030,242	2,033,511	2,065,290	2,050,838	2,534,675
		1,584,252	1,585,843	1,614,526	1,597,365	2,078,340
			1,230,630	1,256,217	1,236,347	1,714,460
				977,759	955,180	1,430,431
					469,787	916,974
						87
						-

Optimal ordering strategy: at 1 orders for January, at 2 orders for February, at 3 orders for March, at 4 order for April and May, and at 6 order for June

Item E

f(1)	1,741,281
f(2)	1,447,049
f(3)	1,065,138
f(4)	718,106
f(5)	344,566
f(6)	150
f(7)	-
Total Cost	**1,741,281**

Matrix for partial costs: cij + f(j)

period	1	2	3	4	5	6
	1,741,281	1,743,320	1,747,148	1,753,421	1,848,494	2,202,480
		1,447,049	1,448,888	1,453,020	1,545,630	1,897,641
			1,065,138	1,067,129	1,157,274	1,507,312
				718,106	805,788	1,153,852
					344,566	776,024
						150
						-

Optimal ordering strategy: Lot- for- lot ordering strategy.

Item F

f(1)	1,741,281
f(2)	5,332,019
f(3)	4,070,883
f(4)	3,631,004
f(5)	1,624,724
f(6)	77
f(7)	-

Matrix for partial costs: cij + f(j)

period	1	2	3	4	5	6
	1,741,281	1,743,320	6,506,855	6,565,950	7,040,497	8,744,850
		5,332,019	5,336,266	5,375,637	5,830,327	7,518,708
			4,070,883	4,090,530	4,525,363	6,197,772
				3,631,004	4,045,980	5,702,417
					1,624,724	3,660,385
						77
						-

Total cost: **1,741,281**

Optimal ordering strategy: at 1 orders for January, at 2 orders for February, at 3 orders for March, at 4 orders for April and May, and at 6 orders for June.

Item G

f(1)	5,922,646
f(2)	4,642,226
f(3)	3,459,895
f(4)	2,110,213
f(5)	1,346,897
f(6)	906
f(7)	-

Matrix for partial costs: cij + f(j)

period	1	2	3	4	5	6
	5,922,646	5,978,677	6,107,774	6,335,331	6,403,437	8,071,735
		4,642,226	4,706,322	4,892,158	4,903,129	6,506,604
			3,459,895	3,604,010	3,557,846	5,096,497
				2,213,513	2,110,213	3,584,041
					1,346,897	2,596,372
						906
						-

Total Cost **5,922,646**

Optimal ordering strategy: At 1 orders for January and February, at 3 orders for March and April, at 5 orders for June, and at 6 orders for June.

Item H

f(1)	428,607
f(2)	340,190
f(3)	268,913
f(4)	195,029
f(5)	104,445
f(6)	824
f(7)	-

Matrix for partial costs: cij + f(j)

period	1	2	3	4	5	6
	428,607	492,712	626,548	873,886	1,395,046	1,970,699
		340,190	406,697	571,314	969,609	1,450,526
			268,913	350,810	626,240	1,012,421
				195,029	347,594	639,040
					104,445	331,679
						824
						-

Total Cost **428,607**

Optimal ordering strategy: Lot- for- lot ordering strategy.

Item I

			Matrix for partial costs: cij + f(j)						
			period	1	2	3	4	5	6
f(1)	2,136,081			2,136,081	2,146,588	2,163,509	2,221,289	2,215,247	2,733,305
f(2)	1,713,777				1,713,777	1,721,751	1,771,433	1,755,918	2,263,544
f(3)	1,199,056					1,199,056	1,240,641	1,215,653	1,712,846
f(4)	797,695						832,156	797,695	1,284,455
f(5)	468,815							468,815	902,182
f(6)	974								974
f(7)	-								-
Total Cost	**2,136,081**								

Optimal ordering strategy: at 1 order for January, February and March, at 4 orders for April and May, at 5 orders for Jun.

Appendix D: DDMRP buffer lever and on hand of both domestic and overseas items

	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Item 1	**Demand**	**3,101**	**3,438**	**4,319**	**8,756**	**10,463**	**8,956**	**7,489**	**3,101**	**11,472**	**13,368**	**5,234**	**7,532**
L=1	Green zone	9,117	11,537	17,545	25,009	29,936	28,590	20,768	23,441	29,687	31,954	27,767	22,629
	Yellow zone	6,543	8,279	12,591	17,948	21,483	20,517	14,904	16,822	21,305	22,931	19,927	16,240
	Red zone	3,683	4,660	7,087	10,102	12,092	11,548	8,388	9,468	11,991	12,907	11,216	9,140
	DDMRP on hand	1,354	7,450	4,349	911	16,697	7,941	14,334	5,378	6,304	16,894	5,422	6,884
	MRP on hand	-	-	-	(4,211)	4,211	-	-	-	-	-	-	-
Item II	**Demand**	**38,824**	**13,480**	**10,816**	**11,688**	**12,088**	**10,472**	**68,104**	**51,704**	**54,456**	**65,848**	**60,640**	**53,888**
L=2	Green zone	154,590	95,825	54,629	52,515	51,993	137,640	197,782	264,556	261,131	274,697	273,835	245,740
	Yellow zone	120,647	74,785	42,634	40,985	40,577	107,419	154,356	206,468	203,795	214,382	213,709	191,784
	Red zone	52,761	32,705	18,645	17,923	17,745	46,976	67,502	90,292	89,123	93,753	93,459	83,870
	DDMRP on hand(t)	31,465	29,571	28,412	43,521	32,705	21,017	8,929	77,243	81,769	105,695	173,550	107,702
	MRP on hand	-	-	(10,816)	10,816	-	-	-	-	-	-	-	-

Item III	Demand	13,347	19,395	12,624	13,174	30,765	33,720	42,722	11,276	18,671	20,983	24,766	22,472
L=3	Green zone	84,628	70,862	70,591	88,351	121,303	167,457	137,016	113,509	79,553	100,624	106,561	100,737
	Yellow zone	79,210	66,325	66,072	82,695	113,537	156,737	128,244	106,242	74,460	94,182	99,739	94,287
	Red zone	25,031	20,959	20,879	26,132	35,878	49,530	40,526	33,573	23,530	29,762	31,518	29,795
	DDMRP on hand(t)	5,423	23,803	6,039	50,243	36,896	17,501	4,877	14,323	52,062	18,342	24,380	13,104
	MRP on hand	-	-	-	-	(9,765)	9,765	-	-	-	-	-	-
Item IV	Demand	37,285	32,742	46,243	23,654	35,745	32,534	21,453	25,673	31,345	24,351	32,353	35,246
L=1	Green zone	105,910	123,537	109,054	112,245	97,679	95,340	84,639	83,375	86,455	93,552	97,697	95,460
	Yellow zone	76,006	88,656	78,262	80,552	70,099	68,421	60,741	59,834	62,044	67,137	70,112	68,507
	Red zone	42,779	49,899	44,049	45,338	39,455	38,510	34,187	33,677	34,921	37,788	39,462	38,558
	DDMRP on hand(t)	18,214	41,011	87,309	41,066	74,524	38,779	38,312	16,859	56,881	25,536	70,453	38,100
	MRP on hand	-	-	(46,243)	46,243	-	-	-	-	-	-	-	-

Item V	**Demand**	**28,492**	**48,294**	**18,534**	**59,283**	**46,235**	**46,374**	**57,231**	**24,352**	**42,356**	**13,425**	**25,352**	**41,632**
L=2	Green zone	191,757	144,708	191,453	188,327	230,592	227,477	194,256	188,156	121,653	123,171	122,072	173,562
	Yellow zone	149,653	112,935	149,416	146,977	179,962	177,530	151,603	146,843	94,942	96,126	95,269	135,453
	Red zone	65,446	49,388	65,342	64,275	78,700	77,637	66,299	64,217	41,520	42,038	41,663	59,236
	DDMRP on hand(t)	31,465	29,571	38,744	67,922	103,592	109,279	63,044	144,626	87,395	63,043	62,651	49,226
	MRP on hand	-	-	-	(59,283)	59,283	-	-	-	-	-	-	-
Item VI	**Demand**	**13,243**	**35,423**	**42,334**	**23,453**	**23,534**	**42,534**	**24,354**	**42,353**	**42,353**	**23,432**	**32,542**	**41,034**
L=3	Green zone	109,501	142,142	158,090	139,519	139,832	141,239	170,634	170,352	168,912	153,587	151,526	141,876
	Yellow zone	102,491	133,042	147,969	130,587	130,880	132,197	159,710	159,446	158,098	143,754	141,826	132,793
	Red zone	32,388	42,042	46,759	41,266	41,359	41,775	50,469	50,386	49,960	45,427	44,818	41,963
	DDMRP on hand(t)	14,423	32,803	36,393	104,435	91,192	104,473	62,139	38,686	15,152	27,382	41,376	21,117
	MRP on hand	-	-	-	-	(23,534)	23,534	-	-	-	-	-	-

All items with different lead time L=1, 2, or 3 and each of them has a delay is highlighted in yellow number on the row of demand amount from January to December 2021. Green, yellow, and red zones which are 3 services zone as DDMRP methodology; DDMRP on hand is available items are calculated in DDMRP method and MRP on hand is available items as conventional MRP is applied.