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Demand Driven Material Requirement Planning

Suitable components and data considerations

School of Technology

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TIIVISTELMÄ

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Todelliseen tarpeeseen perustuva toimitusketjun ja materiaalitarpeiden suunnittelua on esitetty ratkaisemaan tavanomaisen Materiaalitarpeiden metodin ongelmat nykyisissä toimitusketjun olosuhteissa. Tutkimuksen tavoitteena on selittää, minkälainen komponentti sopii DDMRP:lle. Opinnäytetyössä selitetään komponentin määrittelyyn liittyvät prosessit ja tarvittavan data. Tutkimuksessa selitetään myös valmistavien tuotantolaitosten rakenteet Wärtsilä Smart Technology Hub -laitoksen rakenteen määrittelemiseksi.

Tämä tutkimus tarjoaa teoreettisen kuvan tavanomaisesta MRP:stä, nykyisistä toimitusketjun olosuhteista, DDMRP: stä ja tuotantolaitosten prosessirakenteista. Teoreettinen tutkimus on tehty tutkimalla kirjallisuutta, pitämällä kokouksia Wärtsilän vanhemman kehityspäällikön kanssa ja Demand Driven Instituutin järjestämien kansainvälisten webinaarien kautta.

Tutkimuksen tuloksessa esitetään kolme kohtaa sopivan komponentin määrittelemiseksi DDMRP:lle: Määrittelemällä malliin soveltuvan komponentin kuvaus, Decoupling- pisteiden luonti tuoterakenteeseen ja materialipuskureiden määritteleminen ja laskeminen. Tutkimustulos auttaa Wärtsilää ymmärtämään paremmin DDMRP-periaatetta sekä miten voidaan määrittää sopivia komponentteja DDMRP:lle.

Avainsanat: Material Requirement Planning, Demand Driven Material Requirement Planning, Toimitusketjun ominaisuudet ja olosuhteet, Tuotantolaitosten prosessirakenteet.

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ABSTRACT

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Demand Driven Material Requirement has been presented to solve conventional material requirement planning problems in today's Supply Chain circumstances, this study aims to explain what kind of component is suitable for DDMRP. Study is explaining the process and data considerations of defining the component. The study also explains manufacturing plant structures for defining Wärtsilä Smart Technology Hub plant structure.

This study provides a theoretical view of conventional MRP, today's Supply Chain circumstances, DDMRP and Manufacturing plant structures. The theoretical study has been compiled via viewing literature, meetings with Wärtsilä's Senior development manager and via participating international DDMRP Webinars by Demand Driven Institute.

The result of the study presents three point to define the suitable component for DDMRP: Defining the component to be beneficial to be run by DDMRP, Decoupling point positioning and Calculating Buffer zones and levels. As product having data for these points, component is suitable for DDMRP. Plant structure for STH has been defined. The result of the study will support Wärtsilä for future, to understand DDMRP principle and how to and the process of finding suitable components for DDMRP.

Keywords	Material Requirement Planning, Demand Driven Material Requirement Planning, Supply Chain Characteristics and circumstances, Manufacturing plant structures

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GLOSSARY

DDMRP	Demand Driven Material Requirement Planning
MRP	Material Requirement Planning
SC	Supply Chain
STH	Wärtsilä Smart Technology Hub
MPS	Master Production Schedule
BOM	Bill of Material
mBOM	Matrix Bill of Material
LT	Lead time
S&OP	Sales and Operations plan
Q	Quarter
MLT	Manufacturing lead time
CLT	Cumulative lead time
PLT	Purchasing lead time
FOQ	Fixed Order Quantity
POQ	Periodic Order Quantity
L4L	Lot for Lot
EOQ	Economic order Quantity
MOQ	Minimum Order Quantity

ROA	Return On Assets
US	United States of America
MRPII	Manufacturing Resource planning
ERP	Enterprise Resource Planning
SKU	Stock Keeping Unit
DDI	Demand Driven Institute
ROI	Return on Investment
DLT	Decoupled Lead time
ADU	Average Daily Usage
DAF	Demand Adjustment Factor
OST	Order Spike Threshold
OSH	Order Spike Horizon
OST (50%)	Total Red zone times 50%
OST (RS)	Red Base
TOG	Top of Green zone
TOY	Top of Yellow zone
TOR	Top of Red zone
AVG	Average
GW	Giga Wat

VUCA World	Volatile, Uncertain, Complex & Ambiguous World
AI	Artificial Intelligence

1 INTRODUCTION

The thesis is done to understand the conventional material requirement planning method, what is the new normal in today's Supply chain characteristics and how the conventional MRP performs in the new normal. Demand Driven Material Requirement Planning is presented to solve conventional MRP's problem areas in the new normal and to understand the basic principles and phases of DDMRP. Manufacturing plant structures are presented to understand the way of manufacturing different products in different industries and to point what structure Wärtsilä Smart Technology Hub plant would have.

Understanding properly today's Supply Chain characteristics, conventional MRP performance problems and way of DDMRP is solving these problems, the suitable component can be pointed out with process of identifying and data considerations. Lack of understatement about the process and needed data can increase uncertainty and disallow effectiveness of DDMRP.

1.1 Research Objectives and questions

Research question 1

1. What kind of component is suitable for Demand Driven Material Requirement Planning in Wärtsilä Smart Technology Hub Environment?

    - In this thesis the student will study the theory of material requirement planning models. Studying of MRP models will create good knowledge of what is differences in MRP models and which one is suitable for different kinds of components in different kinds of environments. The student will also study theory of operation models to identify the STH operation model. Objective for studying that the student will understand and will detect what kind of component is suitable for Demand Driven

Material Requirement Planning in Wärtsilä Smart Technology Hub Environment.

Research Question 2

1. What is the process of identifying a component which is suitable to DDMRP?

- The thesis will answer a question about the process of identifying suitable and not suitable from existing components to Demand Driven Material Requirement Planning in STH environment. What kind of data needs to be collected and what data needs to be known before identifying process can be done. The thesis will describe what kind of process is needed to be done to identify the suitable component. By knowing the process and its parameters and component data, Wärtsilä can apply this Thesis to identify a component which is a suitable for DDMRP in STH environment. Wärtsilä can decrease the time used in identifying suitable component for DDMRP. With decrease of time used on the process, Wärtsilä uses less resources to identify suitable component, this improves efficiency of used resources and makes the process of identifying a suitable component to DDMRP to be faster.

1.2 Structure of the thesis

This thesis approaches the research questions by theoretical research. Chapter 2 explains the literature of the study, how conventional Material Requirement Planning is used to calculate supply order generation and manage inventory status? What is the new normal of Supply Chain characteristics today? What are the conventional planning weaknesses in today's Supply Chain? How's Demand Driven Material Requirement Planning is driven, generating supply orders and managing inventory with buffers? What are the differences in manufacturing plant structures?

Chapter 3 explains for which company the thesis is done. This chapter gives an overview of Wärtsilä Oyj and the department for which the thesis is done and why the thesis is done. Chapter also presents the formats of material which the thesis is done.

The findings for key questions from the literature & materials are presented and explained in depth in Chapter 4.

Chapter 5 presents conclusions & discussions, the summary of key findings, how the thesis can help Wärtsilä in the future and the thesis limitations.

1.3 Research method

This thesis approaches the research questions by theoretical research. Most of the research is done by reviewing literature from books, published white papers, documents, theses and analyses. Information gathering is also done via international webinars, questions and answers are used as a material for thesis. The aim of the thesis and discussions are conducted via meetings held with Senior Development manager.

2 LITERATURE

To understand why Demand Driven Material Requirement Planning model has been developed, the way of conventional planning is working must be known and supply chain circumstance differences of 1960's versus today's world. Chapter 2.1 explains basic principles of Material Requirement Planning and related processes in firm that is needed to understand how conventional MRP is working. Book Operations Management Processes and Supply Chains Twelfth Edition is describing MRP and its related processes well. It is recommended that the reader of this thesis goes through chapter 11 Resource planning from the book and has an APICS Dictionary, The essential Supply chain reference Fourteenth edition as a terminology. Both texts describe MRP and it processes well. Chapter 2.2 and 2.3 explains the new normal and conventional MRP characteristics in it. When understanding DDMRP process and characteristics this paper can be used as a simple guideline for how Demand Driven MRP method works. For deeper understanding of DDMRP, I recommend DDMRP book by Ptak & Smith as well the articles and white papers published by https://www.demanddriveninstitute.com/.

2.1 Material Requirement Planning

In Operations Management Processes and Supply Chains Twelfth Edition, Material Requirement Planning is described as:

"A computerized information system developed specifically to help manufacturers manage dependent demand inventory and schedule replenishment orders"

MRP key inputs are Master Production Schedule (MPS), Bill of Materials database and inventory record database as shown as figure 1. Using this data MRP system identifies that the actions the planners must take to stay on schedule, such as releasing new production orders, adjusting order quantities and expediting late orders. APICS dictionary describes Material Requirements Planning as:

"A set of techniques that uses bill of material data, inventory data, and the master production schedule to calculate requirements for materials. It makes recommendations to release replenishment orders for material. Further, because it is time-phased, it makes recommendations to reschedule open orders when due dates and need dates are not in phase. Time-phased MRP begins with the items listed on the MPS and determines (1) the quantity of all components and materials required to fabricate those items and (2) the date that the components and material are required. Time-phased MRP is accomplished by exploding the bill of material, adjusting for inventory quantities on hand or on order, and offsetting the net requirements by the appropriate lead times".

Lead time is the time which elapses between the issuance of a work order to the assembly floor and work completion.

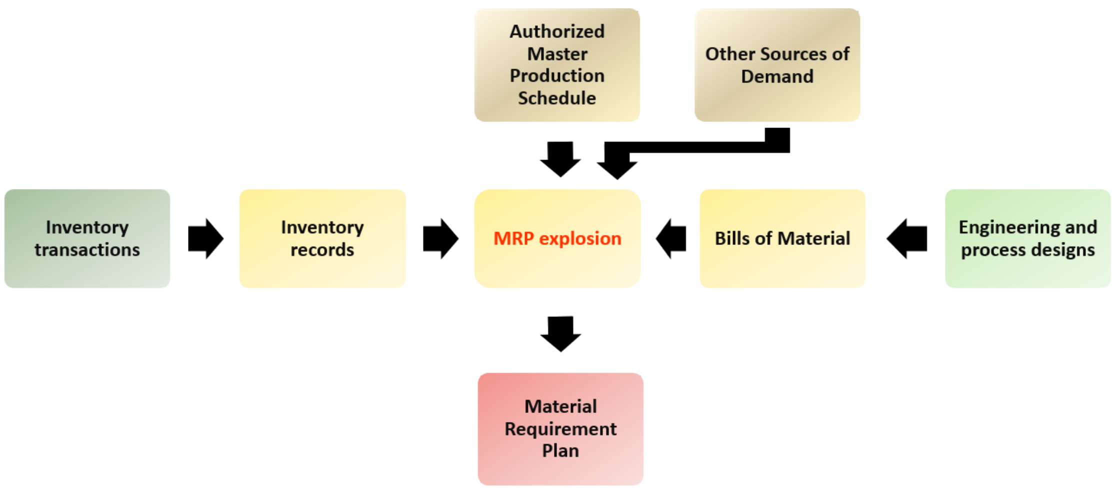


Figure 1. Material Requirement Plan Inputs

2.1.1 Dependent and Independent Demand

Dependent demand is the demand for an item that occurs because the quantity required varies with the production plans for other items held in the firm's inventory. Components that go through one or more operations to be transformed into a product has a dependent demand, because manufacturing of components are dependent of manufacturing the parent item, the product. Independent demand is demand for finished goods, parts required for destructive testing and service parts, item that is unrelated to the demand of other items. Demand of an item that has independent demand varies on many factors, market situation of the item, environmental factors, season and more. Figure 2 shows dependent and independent demand in Bill of Material.

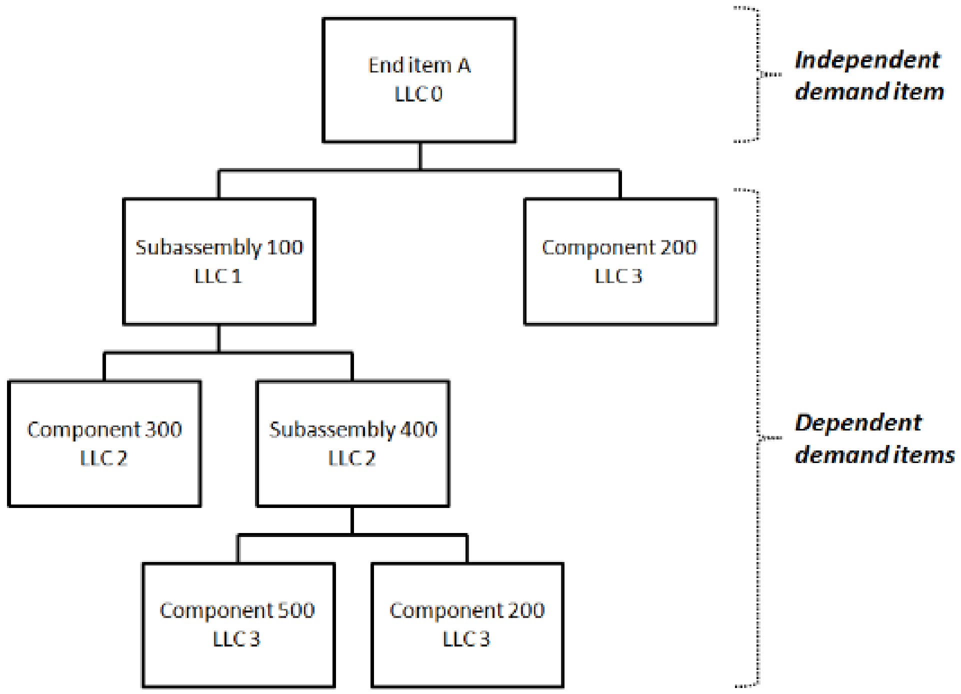


Figure 2. Example of BOM and item demand types

2.1.2 Material requirement planning explosions

MRP explosion is a process that converts the requirements of various final product into material requirements plan that specifies the replenishment schedules of all the subassemblies, components and raw material needed to produce final products. Inputs to MRP explosion are Bill of Material, Inventory Records and Master Production Schedule. Outputs to MRP explosion are requirement and performance reports, schedules and notices to help the planner control dependent demand inventories /3/.

2.1.3 Bill of material (BOM)

APICS dictionary describes BOM as:

"A listing of all the subassemblies, intermediates, parts, and raw materials that go into a parent assembly showing the quantity of each required to make an assembly. It is used in conjunction with the master production schedule to determine the items for which purchase requisitions and production orders must be released. A variety of display formats exist for bills of material, including the single-level bill of material, indented bill of material, modular (planning) bill of material, transient bill of material, matrix bill of material, and costed bill of material"

A product that is manufactured from one or more components is called a parent and component is an item that goes through one or more operations to be transformed into or become a part of one or more parents. Four terms that are frequently described used to describe inventory items are end items, intermediate items, subassemblies and purchased items. An end item typically is the final product (in this case Finished good, figure 3) sold to the customer, it is a parent but not a component. Intermediate item is an item that has at least one parent and at least one component. Subassembly is an intermediate item that is assembled from more than one component. Purchased item is an item that comes from supplier, it has one or more parents but no components. /3/

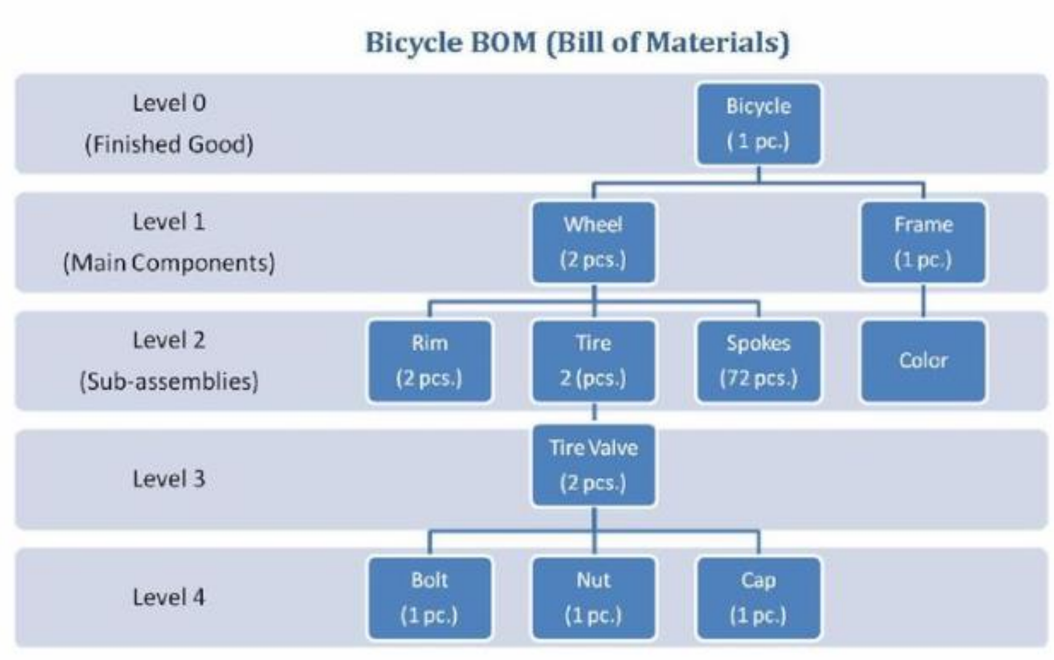


Figure 3. Bicycyle BOM example.

2.1.4 Inventory records

APICS dictionary describes Inventory records as:

"*A history of the inventory transactions of a specific material*"

The inventory records are used to track information on the status of each item by time period. This includes **gross requirements, scheduled receipts**, **and the projected amount on hand**, **planned receipts** and **planned order releases**. It includes other details for each item as well, like the supplier, the lead-time, and the lot size.

Gross requirements are the total demand (independent and dependent demand) derived from all parent production plans before netting of on-hand and schedule receipts. Later in this chapter zeros in figures is shown as blanks, except in the projected on-hand inventory row, even if its zero or negative number (see figure 4).

Item: C Subassembly	Order policy : 230 units Lead time : 2 Quarter				
		Period 1			
		Q1	Q2	Q3	Q4
Gross requirements		150			120
Schedule receipts		230			
Projected on-hand inventory	37	117	117	117	-3
Planned receipts					
Planned order releases					

Gross requirements are the total demand for the items. Projected on-hand inventory in Q1 is 37 + 230 – 150 = 117 units

Shortage will occur if scheduler doesn't schedule more items to be manufactured

Figure 4. MRP record for Component B subassembly C

The MRP system works with release dates to schedule production and delivery for components and subassemblies. The system logic anticipates the removal of all materials required by a parent's production order from inventory at the beginning of the parent item's lead time.

Projected on-hand Inventory is an estimate of amount of inventory available next time period after gross requirements have been satisfied. Chapter 2.1.7 describes calculation formula and example for Projected on-hand Inventory.

Schedule Receipts, sometimes called **open orders** are orders that have been placed but not yet completed. Stages for orders can be; being processed by supplier, being transported to place, waiting for components or waiting for machining.

Planned receipts, planning for the receipt of new order will keep the projected on-hand inventory balance from dropping below zero. The planned receipt row is developed as follows:

1. On-hand inventory is projected until shortage appears. The planned receipt is scheduled for the quarter in which shortage will occur. The new planned receipt keeps Projected on-hand inventory equal or above zero units, it will exceed zero when the lot size exceeds requirements in the quarter is planned to arrive.
2. Next shortage is projected and needs seconds planned receipt. Process is repeated until the end of the planning horizon by proceeding column by column through the MRP record, filling in planned receipts as needed and completing the projected on-hand inventory row. See Figure 5.

Item: C Subassembly					**Order policy : 230 units Lead time : 2 Quarter**			
	Period 1				P2			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Gross requirements	150			120		150	120	
Schedule receipts	230							
Projected on-hand inventory 37	117	117	117	227	227	77	187	187
Planned receipts				230			230	
Planned order releases		230			230			

To cover shortage 3 units, 230 units are added to Planned order release with of set of -2 quarters from needed date Q4. 117 + 230 – 120 = 227 units

Shortage 77 – 120 = – 43 units will occur unless it is covered. Adding second planned receipt bring balance to 77 + 230 – 120 = 187 units

Figure 5. Completed inventory record for item C subassembly

Planned order release indicates when an order for a specified quantity of an item is to be issued. Planned order release must be placed in the proper time frame that it will support a manufacturing order.

2.1.5 Master Production Schedule

Master production schedule is a line on the master schedule grid that reflects the anticipated build schedule for those items assigned to the master scheduler. The master scheduler maintains this schedule, and in turn, it becomes a set of planning numbers that drives material requirements planning. It represents what the company plans to produce expressed in specific configurations, quantities, and dates. The master production schedule is not a sales item forecast that represents a statement of demand. The master production schedule must take account the forecast, the production plan, and other important considerations such as backlog, availability of material, availability of capacity, and management policies and goals. Aspects of MPS:

1. The sums of the quantities in the MPS must equal those in the sales and Operations plan. This consistency between the plan is desirable because of the economic analysis done to arrive at the sales and operations plan.
2. The production quantities must be allocated efficiently over time. The specific mix of product types – the number of each type as a percent of the total quantity – is based in historic demand and on marketing and promotional considerations. The planner must select lot sizes for each product type, taking account economic factors such as inventory carrying costs and production setup costs.
3. Capacity limitations and bottlenecks, such as labor or machine capacity, working capital or storage place, may determine the timing size of MPS quantities. The planner must know these limitations by recognizing that some product types require more resources that others and setting the timing and the size of the production quantities accordingly.

The operation first create prospective MPS to test if it meets the schedule with the resources; workforce, machine capacities, over time and subcontractors provided for in the sales and operations plan. Then operations revise the MPS until a schedule that satisfies all of the resource limitations is developed or until it is determined that no possible schedule can be developed. The production plan is later revised to adjust production requirements or increase authorized resources. When the managers have accepted possible prospective MPS, Operations uses the authorized MPS as an input to MRP. Operations then determine specific schedules for component assembly and production. Real performance data such as inventory levels and shortages are inputs to preparing the prospective MPS for the next period, the master production scheduling process is repeated from one period to next one, see figure 6.

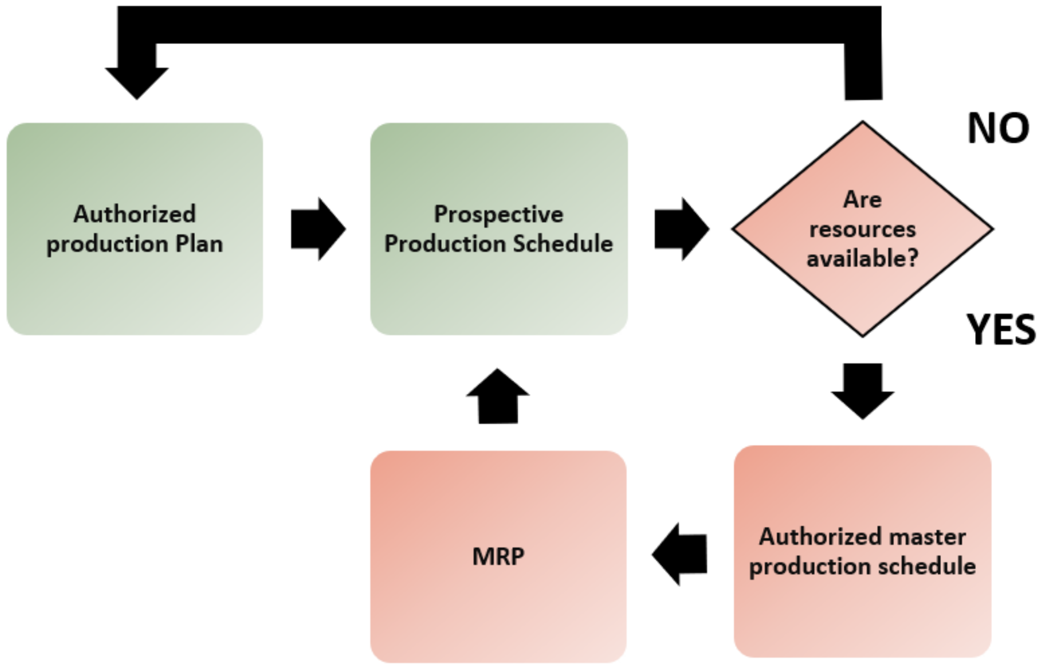


Figure 6. Master Production Scheduling Process.

2.1.6 Sales and Operations plan

A plan of future aggregate resource levels so that supply is in balance with demand. S&OP states a company's or department's production rates, workforce levels, and inventory holdings that are consistent with demand forecasts and capacity constraints. The S&OP is a time-phased plan, meaning that is projected for several time periods into the future /3/.

APICS Dictionary describes S&OP as:

"A process to develop tactical plans that provide management the ability to strategically direct its businesses to achieve competitive advantage on a continuous basis by integrating customer focused marketing plans for new and existing products with the management of the supply chain. The process brings together all the plans for the business (sales, marketing, development, manufacturing, sourcing, and financial) into one integrated set of plans. It is performed at least once a month and is reviewed by management at an aggregate (product family) level. The process must reconcile all supply, demand, and new product plans at both the detail and aggregate levels and tie to the business plan. It is the definitive statement of the company's plans for the near to intermediate term, covering a horizon sufficient to plan for resources and to support the annual business planning process. Executed properly, the sales and operation planning process links the strategic plans for the business with its execution and reviews performance measurements for continuous improvement"

As it has been before announced earlier the Sales and Operation Plan is where the unit demand quantities come to the Master Production Schedule and in the MPS demand quantities are transformed into supply quantities.

2.1.7 Developing a Master Production Schedule

In Operations Management Processes and Supply Chains Twelfth Edition, Developing Master Production Schedule is described as:

The process of developing an MPS has two steps:

1. Calculate Projected On-Hand Inventories

Calculating Projected On-Hand Inventories is an estimate of the amount of inventory available each time period after demand has been satisfied. Time periods can be days, months, quarters or years, varying the product principles such as manufacturing times, material procurement times and market demands.

$$\begin{pmatrix} \textit{Projected on} \\ \textit{hand inventory} \\ \textit{at end of this period} \end{pmatrix} = \begin{pmatrix} \textit{Onhand inventory} \\ \textit{at end of last period} \end{pmatrix} + \begin{pmatrix} \textit{MPS quantity due} \\ \textit{at start of this period} \end{pmatrix} - \begin{pmatrix} \textit{Projected requirements} \\ \textit{this period} \end{pmatrix}$$

For the projected requirements for this period the scheduler uses whichever is larger – the forecast if the customer orders booked – recognizing that the forecast is subject to error. If actual booked orders exceed the forecast, the projection will be more accurate if the scheduler uses the booked orders because booked orders are a known quantity. Conversely, if the forecast exceeds booked orders for a period, the forecast will provide a better estimate of the requirements needed for that week because some orders may yet come in, see figure 7.

Item: X	Period 1	
Quantity on hand: 55	Q1	Q2
Forecast	30	30
Customer orders (booked)	38	27
Projected on-hand inventory	17	-13
MPS Quantity	0	0

Forecast is less than orders in quarter 1; Projected on-hand inventory balance =55 + 0 – 38 = 17

Forecast exceeds booked orders in quarter 2; Projected on-hand inventory balance = 17 + 0 – 30 = -13. The shortage signals is needed to schedule an MPS quantity for completion in quarter 2

Figure 7. Example: MPS for Period 1, Quarter 1 and 2.

2. Determine the Timing and Size of MPS Quantities

The goal of determining the timing and size of MPS quantities is to maintain a nonnegative projected on-hand inventory balance. As shortages in inventory are detected, MPS quantities should be scheduled to cover them, in this example below, 150 units is added to MPS start, shown in figure 8, MPS start column indicates the quarters in which production of the MPS quantities must began. The first MPS quantity should be scheduled for the period when the projected on-hand inventory reflects a shortage, such as quarter 2 in figure 7. The scheduler adds the MPS quantity to the projected on-hand inventory and searches for the next period when a shortage occurs. The shortage signal is needed for a second MPS quantity and so on. Figure 8 shows an MPS for the next 8 quarters. A shortage of 13 units in quarter 2 will occur unless the scheduler provides for an MPS quantity for that period. The unit lead time is 1 quarter in this example. When the MPS quantity is scheduled, the updated projected inventory balance for quarter 2 is

$$Inventory = \begin{pmatrix} 17\ units\ in\ inventory \\ at\ the\ end\ of\ quarter\ 1 \end{pmatrix} + \begin{pmatrix} MPS\ quantity \\ of\ 150\ units \end{pmatrix} - \begin{pmatrix} Forecast\ of \\ 30\ units \end{pmatrix} = 137\ units$$

Item: X								Order policy : 150 Units Lead time : 1 Quarter
	P1				P2			
Quantity on hand: 55	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Forecast	30	30	30	30	35	35	35	35
Customer orders (booked)	38	27	24	8				
Projected on-hand inventory	17	137	107	77	42	7	122	87
MPS Quantity		150					150	
MPS start	150					150		

The time needed for assembilg 150 unit is 1 quarter → Assembly must start in Q1 to have units ready for Q2.

On-hand inventory balance = 17 + 150 – 30 = 137. Shortage is avoided by scheduling of 150 units to MPS Quantity for Q2

Figure 8. MPS for Quarters 1 – 8.

To avoid the shortages scheduler proceeds column by column through the MPS until it reaches the end, filling in the MPS quantities as needed. Units of -137 in projected inventory will satisfy forecasted demand until quarter 7, if the scheduler does not add more units for assembly in quarter 6 the shortage will occur in Q7, 7 + 0 – 35 = - 28 units. When added 150 units to MPS quantity in Q7 the inventory balance is 7 + 150 – 35 = 122 units, see figure 8.

2.1.8 Available-to-Promise quantities and inventory

In Operations Management Processes and Supply Chains Twelfth Edition, ATP inventory & quantities are described as:

"Available-to-Promise inventory is a quantity of units that marketing can promise to deliver on specific date to a customer. It is the difference between the customer orders already booked and the quantity that operations is planning to produce"

As new orders from customers are accepted, the ATP inventory is reduced to reflect the commitment of the firm to ship those quantities, but the actual inventory stays unchanged until the order is removed from inventory and shipped to a customer.

An available-to-promise inventory is associated with each MPS quantity because the MPS quantity specifies the timing and size of new stock that can be ear marked to meet future bookings. ATP quantity row have been added to figure 9. The ATP in quarter 2 is the MPS quantity minus booked customer orders until the next MPS quantity, 150 – (27 + 24 + 8 + 0 + 0) = 91 units. The ATP indicates to marketing that, of the 150 units scheduled for completion in quarter 2, 91 units are uncommitted and total new orders up to that quantity can be promised for delivery as early as quarter 2. In quarter 7 the ATP is 150 units because there are no booked orders in Q7 and beyond.

$$ATP\ inventory = \text{MPS quantity} - \begin{pmatrix} Sum\ of\ booked \\ Customer\ orders \\ until\ next \\ MPS\ quantity \end{pmatrix}$$

Item: X					Order policy : 150 Units Lead time : 1 Quarter			
	P1				P2			
Quantity on hand: 55	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Forecast	30	30	30	30	35	35	35	35
Customer orders (booked)	38	27	24	8				
Projected on-hand inventory	17	137	107	77	42	7	122	87
MPS Quantity		150					150	
MPS start	150					150		
Available to promise (ATP) inventory	17	91					150	

The total of customer orders booked until the next MPS receipt is 38 units. ATP = 55 + 0 – 38 = 17.

The total of customer orders booked until the next MPS receipt is 59 units. ATP = 91 units.

Figure 9. MPS records with ATP row.

If the customer order requests exceed ATP quantities in those time periods, the MPS must be changed before the customer orders can be booked or the customers must be given a later delivery date, when the next MPS quantity arrives, see figure 9.

2.1.9 Freezing the MPS

In Operations Management Processes and Supply Chains Twelfth Edition, Freezing the MPS is described as:

The MPS is the basis of all end item, subassembly, component and materials schedules. For this reason, changes to the MPS can be very costly, particularly if they are made to MPS quantities soon to be completed. Decreases in MPS quantities can result in unused materials or components and valuable capacity being used to create products not needed. Similar cost occurs when forecasted need dates for MPS quantities are changed. Increase in an MPS quantity can result in material shortages, delayed shipment to customer and excessive expediting costs. /3/

2.1.10 Planning Factors

The planning factors play important role in the MRP systems performance, by manipulating factors wanted performance can be achieved. These factors are lead time, lot-sizing and safety stock.

Planning lead time

Planning lead time is an estimate of time between placing an order for an item and receiving the item in inventory. Accuracy is important in planning lead time, costs can increase if an item arrives sooner to inventory than planned and cost increase occurs when item arrives too late, stockouts, excessive expediting costs or both may occur. Purchased items lead time is the time between order have been sent to supplier and the item have been received, in other words delivery time. Lead time estimating process consist of breaking down following factors:

- Setup time
  - The time required for specific machine, resource, work center, process or line to convert from the production of last piece of item A to the first piece of item B.

- Processing time
    - The time during material is being processed, whether it is a machining operation or an assembly.
- Material handling time between operations
    - The time used in transportation, moving and delivering material during the production or distribution process.
- Waiting time
    - The time during material or item is waiting or stuck in process, material is waiting for machining, assembly line is stopped working or planned material is undelivered in time and next process can't be started.

Each of these factors must be estimated for every operation along the items route. APICS Dictionary describes three relevant Lead Times:

- Manufacturing lead time (**MLT**): The total time required to manufacture an item, exclusive of lower level purchasing lead time. For make-to-order products, it is the length of time between the release of an order to the production process and shipment to the final customer. For make-to-stock products, it is the length of time between the release of an order to the production process and receipt into inventory. Included here are order preparation time, queue time, setup time, run time, move time, inspection time, and put-away time.
- Cumulative lead time (**CLT**): The longest planned length of time to accomplish the activity in question. It is found by reviewing the lead time foreach bill of material path below the item; whichever path adds up to the greatest number defines cumulative lead time.
- Purchasing lead time (**PLT**): The total lead time required to obtain a purchased item. Included here are order preparation and release time; supplier lead time; transportation time; and receiving, inspection, and put-away time. /5/

Lot-Sizing Rules

Lot- Sizing rules determines the timing and size of order quantity. Each item must have signed a lot-sizing rule before planned receipts and planned order releases can be computed. Choice of lot-sizing rules determines the number of setups required and the inventory holding costs for each item. There are two main types of lot sizing: a method to unify in terms of the **period** and another method to unify in terms of the **quantity**, third type is mix of period and quantity standards. Figure 10 presents types and rules of lot sizing.

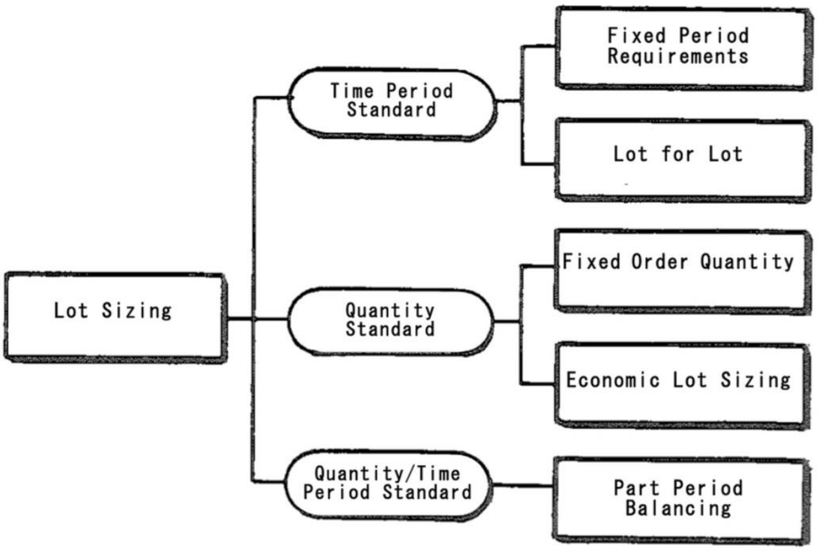


Figure 10. Types and rules of lot sizing /7/.

Operations Management Processes and Supply Chains Twelfth Edition present next three lot-sizing rules:

1. **Fixed order quantity (FOQ)**

Order for quantity is placed each time when order is issued. The Net Requirements are sized by setting FOQ value as an Order Quantity mainly based on the empirical value, and fixing the quantity, as shown in the figure 11. When the Net Requirements within one period are over FOQ value, two ways are possible: the quantity of Net Requirements is used as the order quantity, or the order quantity is obtained by multiplying FOQ value, see figure 11.

Period	1	2	3	4	5	6	7	8	9	Total
Net Requirements	40	15		35		20	5	15	30	160
Scheduled Order	70			70					70	210
Number of Lot Sizing / Fixed Quantity 70										

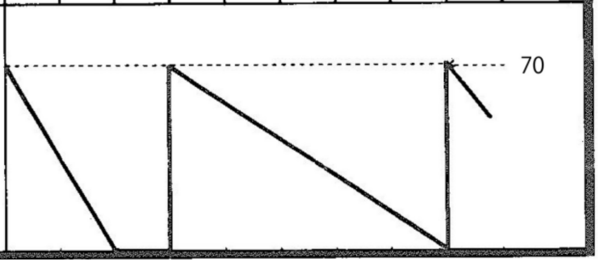


Figure 11. FOQ rule example /7/.

2. **Periodic order quantity (POQ)**

The lot size is equal to the net requirements for a given number of periods A lot-size technique that orders to cover requirements for a variable number of periods based on order and holding costs, see figure 12. POQ is calculated as:

$$\begin{pmatrix} POQ\ lot\ size \\ to\ arrive\ in \\ period\ t \end{pmatrix} = \begin{pmatrix} Total\ gross\ requirements \\ for\ next\ periods, inluding \\ period\ t \end{pmatrix} - \begin{pmatrix} Projected\ on\ hand \\ inventory\ balance\ at \\ end\ of\ period\ t \end{pmatrix}$$

Period	1	2	3	4	5	6	7	8	9	Total
Net Requirements	40	15		35		20	5	15	30	160
Scheduled Order	55			35		25		45		160

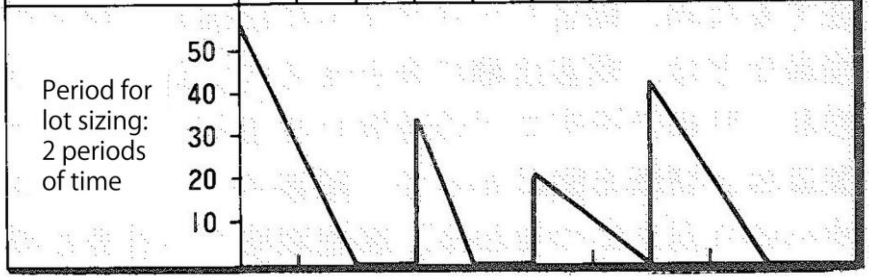


Figure 12. POQ example /7/.

3. **Lot for Lot**

Called Lot for Lot (**L4L**) or Discrete order quantity (**DOQ**). Net requirements occurring for each period are the quantity of order. This method is often used mainly for expensive items and the items whose demand occurs intermittently. In this case the quantity is the same as that of the case in which one period is specified in the fixed period requirements, see figure 13.

Period	1	2	3	4	5	6	7	8	9	Total
Net Requirements	40	15		35		20	5	15	30	160
Scheduled Order	40	15		35		20	5	15	30	160

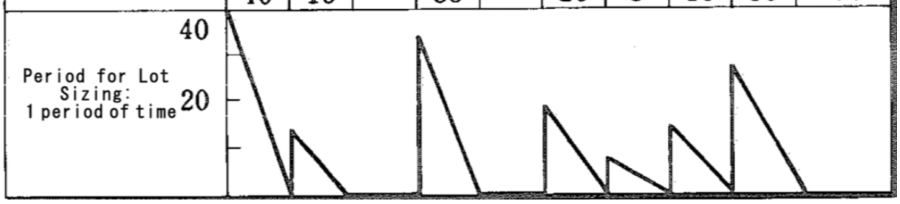


Figure 13. L4L example /7/.

4. **Economic Order Quantity (EOQ)**

Economic Order Quantity refers to the best order quantity to make the total cost minimum by considering the balance between ordering cost and inventory carrying cost, which are contradictory. In Economic Order Quantity as a method for lot sizing by MRP, the Economic Order Quantity for each item is calculated in advance and entered to the item as the EOQ value. lot sizing is performed according to the EOQ value in the same method as Fixed Order Quantity.

5. **Minimum order quantity (MOQ)**

"An order quantity modifier, applied after the lot size has been calculated, that increases the order quantity to a preestablished minimum "/5/.

Safety Stock

Safety stock is a quantity of stock planned to be inventory to protect against fluctuations in demand or supply, safety stock can be generated also as protection against forecast errors and short-term changes in backlog. Safety stock can be generated by setting a quantity for safety stock and keeping it up by planned order releases.

2.1.11 Outputs from MRP

MRP system provides reports, schedules and notices to help planners control dependent demand inventories. MRP explosion process generates material requirements, item attention notices to planners, resource requirement reports and performance reports. MRP translates MPS and other sources of demand into all Material Requirements needed to produce parent items. This process generates the material requirement plan for each component, subassembly and item. MRP generates Action Notices from inventory records that planner uses to make decisions in time frame according to state of inventory, demand. MRP generates Resource Requirement Reports, which is used to show where MPS and MRP plans can and cannot be met, planner monitor and adjust capacity requirements of MRP to modify MRP to meet MPS plans. Performance Reports including Priority reports, Schedule and Financial reports are output from MRP to management, for example management can project inventory and production costs, value of shipment and profits by the MRP plan along with prices and product and activity costs.

2.2 The New Normal

Circumstances under MRP has been developed has dramatically changed. Customer tolerance times have shrunken, customers can nowadays easily find what they want at the price they willing to pay and get it in short period of time. Planning complexity has risen as the customer tolerance times gotten lower. Product variety has risen dramatically, there is many variations of products that is customized to the customer needs. Outsourcing is more prevalent. Production life and development cycles have been reduced dramatically as the technological development has been progressed and accelerated highly, customers want newest product to be more sustainable, functional and cost effective. As the products come more complex, amount of regulations has increased, consumer safety and environmental protection these simply make planning and supply scenarios more complex. The complexity comes from many directions: Ownership, the market, Engineering & Sales and the Supply base. The lack of significant return on technology investment would strongly suggest that this potential, up to this point has been squandered, see figure 14.

Circumstance	1965	2013
Supply Chain Complexity	Low. Supply chains looked like chains – they were more linear. Vertically integrated and domestic supply chains dominated the landscape	High. Supply chains look more like "supply webs" and are fragmented and extended across the globe.
Product Life Cycles	Long. Often measured in years and or decades (e.g. rotary phones)	Short. Often measured in months (particularly in technology)
Customer Tolerance Times	Long. Often measured in weeks and months	Short. Often measured in days with many situations dictating less than 24 hour turns
Product Complexity	Low.	High. Most products now have relatively complex mechanical and electrical systems and micro-systems. Can you even work on a modern car anymore?
Product Customization	Low. Few options or custom feature available.	High. Lots of configuration and customization to a particular customer or customer type.
Product Variety	Low. Example – toothpaste. In 1965 Colgate and Crest each made one type of toothpaste.	High – in 2012 Colgate made 17 types of toothpaste and Crest made 42!
Long Lead Time Parts	Few. Here the word "long" is in relation to the time the market is willing to wait. By default if customer tolerance times were longer it stands to reason that there were less long lead time parts. More so, however, is that fact that supply chains looked different. Most parts were domestically sourced and thus often much "closer" in time.	Many. Today's extended and fragmented supply chains have resulted in not only more purchased items but more purchased items coming from more remote locations.
Forecast Accuracy	High. With less variety, longer life cycles and high customer tolerance times forecast accuracy was almost a non-issue. "If you build it, they will buy it."	Low. The combined complexity of the above items is making the idea of improving forecast accuracy a losing battle.
Pressure for Leaner Inventories	Low. With less variety and longer cycles the penalties of building inventory positions was minimized.	High. At the same time operations is asked to support a much more complex demand and supply scenario (as defined above) they are required to do so with less working capital!
Transactional Friction	High. Finding suppliers and customers took exhaustive and expensive efforts. Choices were limited. People's first experience with a manufacturer was often through a sales person sitting in front of them.	Low. Information is readily available at the click of the mouse. Choices are almost overwhelming. People's first experience with a manufacturer is often through a screen sitting in front of them.

From Demand Driven Performance – Using Smart Metrics (Debra Smith and Chad Smith, McGraw-Hill, 2013)

Figure 14. Supply Chain characteristics /1/.

If the rules behind the MRP software have been changed then the outdated software cannot match the wanted way to new rules. In recent years industry and software providers have attempted to respond to increasing complexity with more sophisticated software applications, applications that uses the same old rules at its core. Responding to new complex circumstances with old complex solutions creates ineffectiveness in all functions.

2.3 Conventional MRP weaknesses in the New Normal

As the MRP is operated by 1960's rules it cannot keep up with twenty-first century's without updating it. There are three areas that point major issues with the rules and tools of conventional planning featuring MRP

2.3.1 Return on Asset Performance Degradation

DDMRP by Ptak & Smith presents figure below that shows ROA decrease in US firms. As the evolution of MRP systems are shown it can be stated that impact of the widespread adoption of MRP, MRP II and ERP systems has not significantly helped companies manage themselves to better Return on Assets Performance, see figure 15.

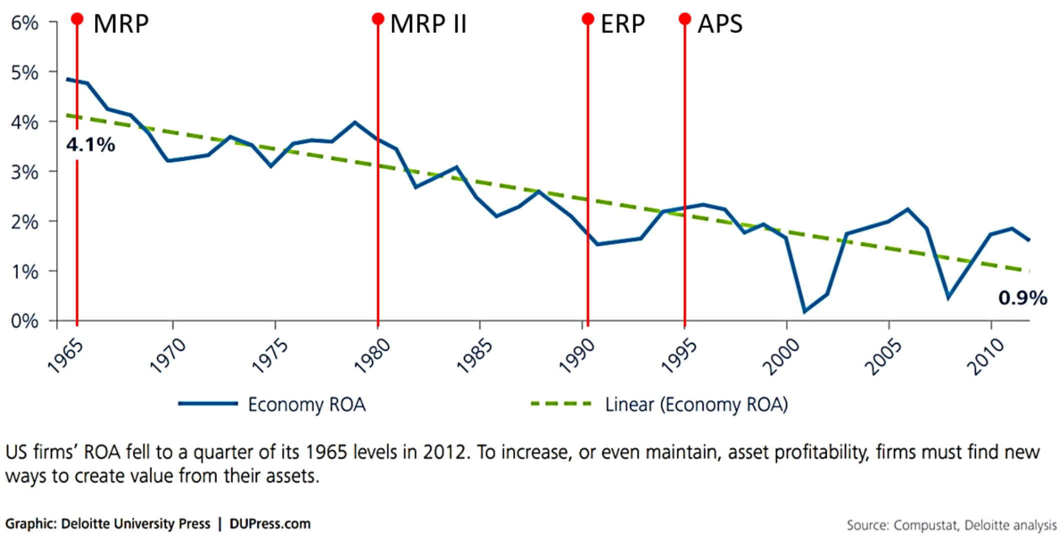


Figure 15. ROA decrease in US firms with evolution of MRP systems.

2.3.2 Work around proliferation

Work-Around the system using spreadsheets as a tool to work with MRP systems shortcomings. Data is extracted out of the planning system and put into a spreadsheet. The data is then organized and manipulated as the planner wants. Data is then put back to the system over riding many of the original data sets, many call this “Excel Hell”. As the data is modified it starts to contain more and more distortions which lead more and more distorted planning result.

Orlicky’s Material Requirement Planning, Third edition, Chapter 3 presents two reports: Report by Aberdeen Group in November 2009 shows 135 Companies using spreadsheets for demand management, see figure 16.

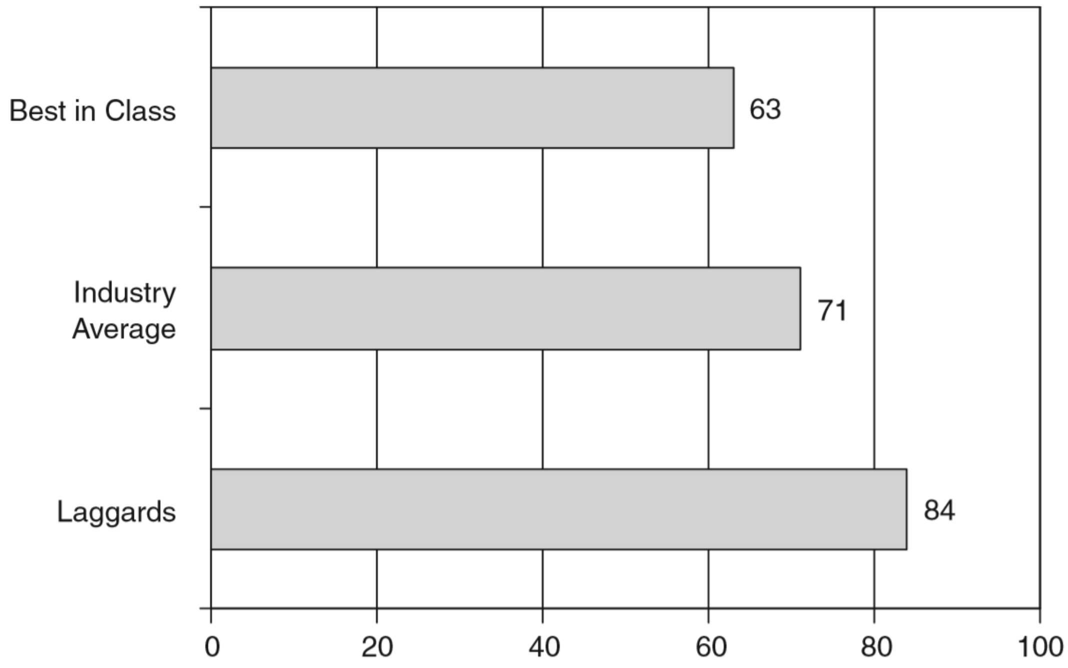


Figure 16. Aberdeen Group, "Demand Management" Boston, November 2009 /10/.

- 63 percent of the best-in-class (top 18 percent) companies reported that they used spreadsheets for their demand management.
- 71 percent of the industry average (middle 54 percent) performers reported the use of spreadsheets for demand management.
- 84 percent of laggard companies (bottom 28 percent) used spreadsheets.

A survey from www.beyondmrp.com , *"Do employees develop "work-arounds" using spreadsheets and Access databases, because they feel they can't work effectively within the Formal Planning System"* /10/, see figure 17:

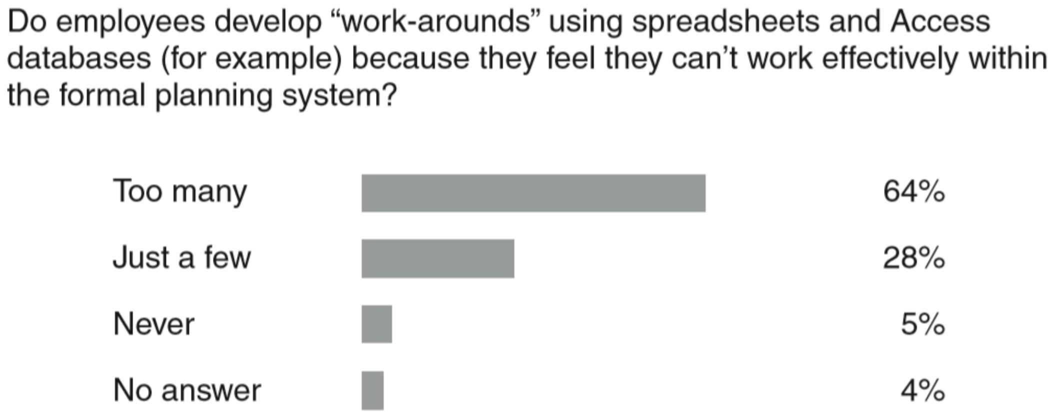


Figure 17. beyondmrp.com survey results /10/.

The results of these two surveys show that for the most companies there is lack of trust that MRP is providing an accurate picture of what is required and when it is required. In addition these reports indicate the inability of ERP companies to evolve MRP rules and tools to acceptable level or their ambivalence about such evolution.

2.3.3 Inventory Bimodal Distribution

Too much the wrong stuff and too little the right stuff, inventory bimodal distribution means that company has two points in inventory, a point where company has too little inventory and a point where there is too much inventory, the inventory quantity fluctuates between these points and the optimal quantity is hard to reach with conventional MRP system tools, see figure 18.

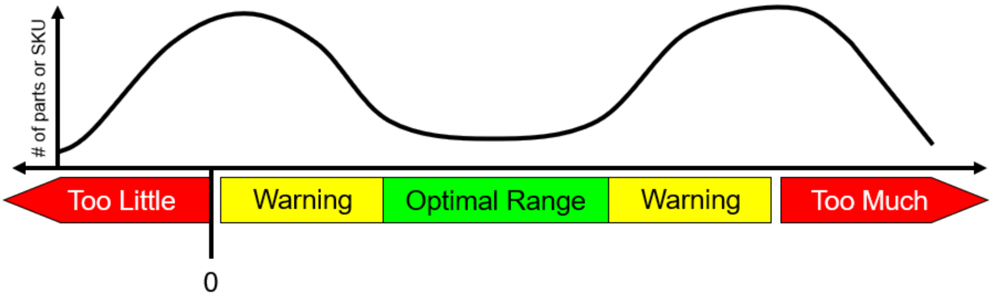


Figure 18. Bimodal distribution illustrated, number of SKU versus optimal inventory range /1/.

In Book DDMRP by Ptak and Smith they say Demand Driven Institute has done a survey in 2011- 2014 about inventory bimodal distribution with over 500 companies responding, 88% of companies report that they have experienced bimodal inventory pattern. Three primary effects of the bimodal distribution are evidence in most companies:

1. High inventories
2. Chronic and frequent shortages
3. High bimodal-related expenses

All these effects have high impact expenses and resource allocation, there is resources tied into inventory when those resources would be useful to be used somewhere else. Material flow is affected, which mean additional expenses and longer customer delivery times. The MRP system is not performing cost and time effectively and it is not responding to demand signals accurately enough.

2.3.4 Distortions to Flow: Bullwhip effect

To truly understand why conventional MRP system is not responding and potential solution to today’s world market circumstances the importance of Flow must be understood. All for-profit entities have the same objective, to drive shareholder equity. To drive shareholder equity you need the right rules and tools to meet the objective, in fact there is a basic principle that adapts company rules and tools to meet the objective, Plossl's First Law: *All benefits will be directly related to the speed of flow of information and materials*. All benefits mean things that most companies measure and highlight:

- Service
- Revenue
- Quality
- Inventories
- Expenses
- Cash

With good flow of information and material the wanted level for benefits can be achieved and better return on investment performance. Thus rules and tools of a business should be built around the *protection and promotion of flow*. When the system cannot perform good enough with the changes in demand, distortions to relevant information and material occurs and bullwhip effect is created, see figure 19. APICS Dictionary describes the Bullwhip effect as:

"An extreme change in the supply position upstream in a supply chain generated by a small change in demand downstream in the supply chain. Inventory can quickly move from being backordered to being excess. This is caused by the serial nature of communicating orders up the chain with the inherent transportation delays of moving product down the chain. The bullwhip can be eliminated by synchronizing the supply chain"

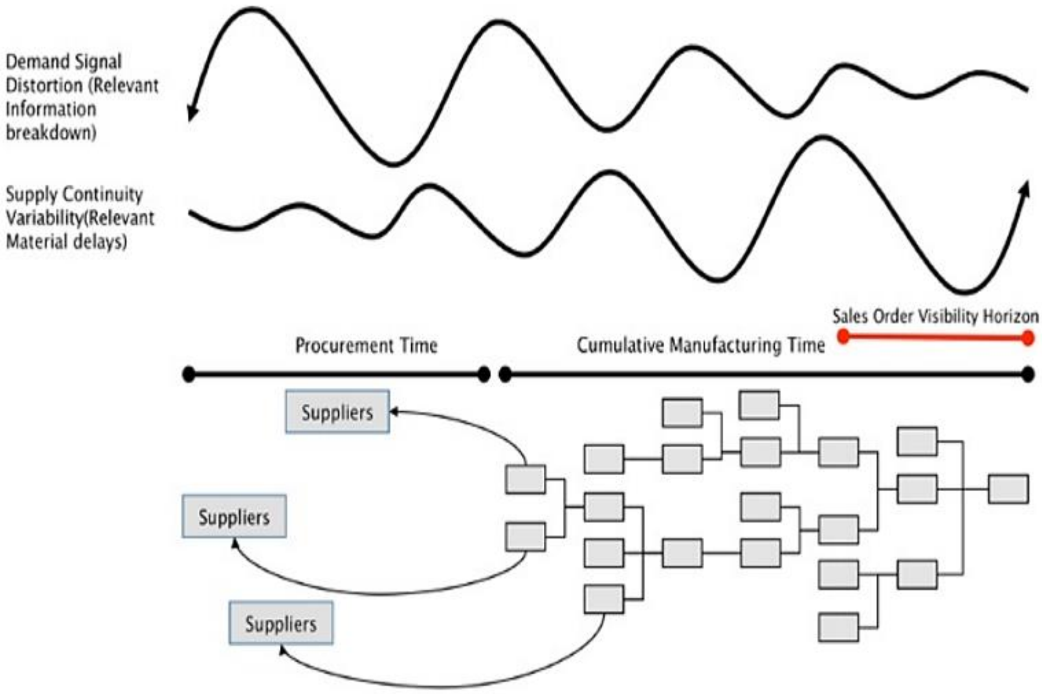


Figure 19. Bullwhip effect of demand signal & supply variability in the system /1/.

As the signal variability is changing and is not controlled in demand and supply, product lead time expands while output decays. Significant expenses are expected when trying to fix lead time and output with old rules and tools, see figure 20.

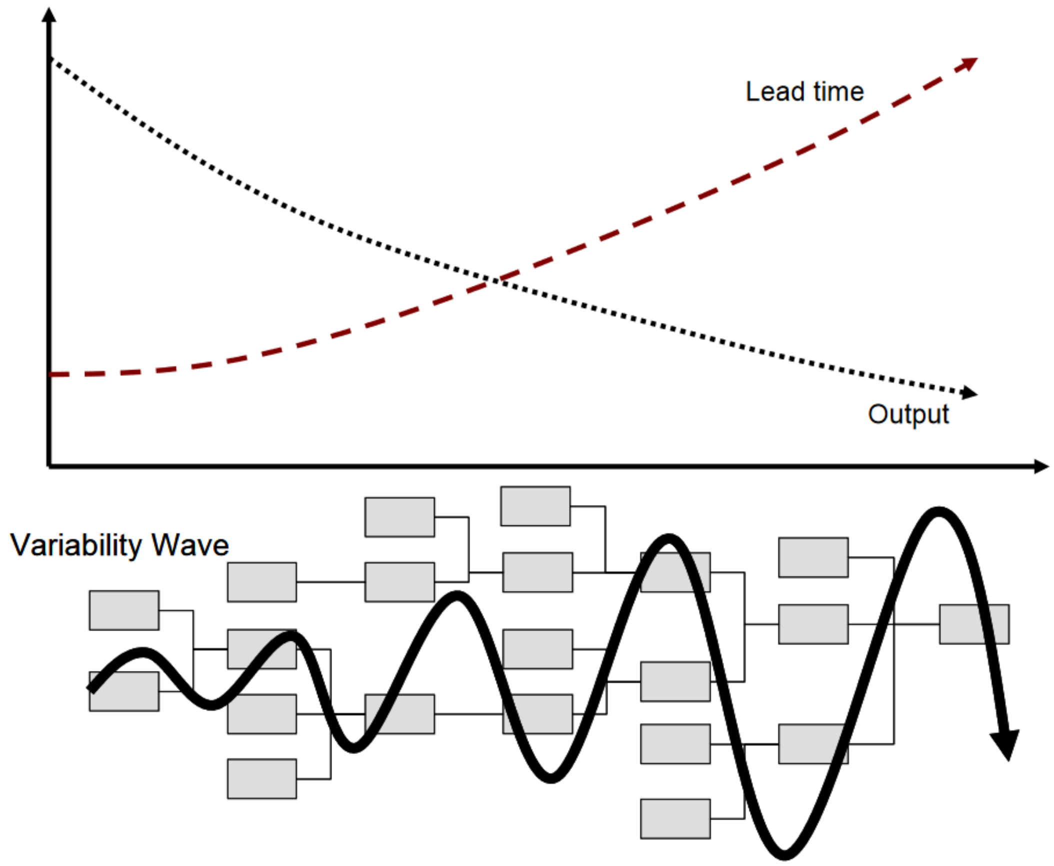


Figure 20. Distortions in flow reflects to Lead time and Output performances /11/.

The bullwhip effect should be controlled with more modern and synchronized system to prevent having to spend significant amount of resources and expenses. Trying protect and promote the flow with system that cannot handle the new market circumstances is a loss of resources and decrease of Return on Investment to a company, companies just cannot expect to get high results by using conventional MRP to protect and promote the flow when it is not meeting and performing the way of new market circumstances.

2.4 Demand Driven Material Requirement Planning (DDMRP)

Demand Driven Material Requirement Planning was introduced in the third edition of Orlicky's Material Requirement Planning (2011) as an alternative planning and control logic. DDMRP combines relevant aspects of MRP and Distribution Requirement Planning (DRP) with the pull and visibility emphases defined by Lean and The Theory of Constrains and variability reduction by Six Sigma (figure 21). In particular, demand driven means respond to predictable & unpredictable changes.

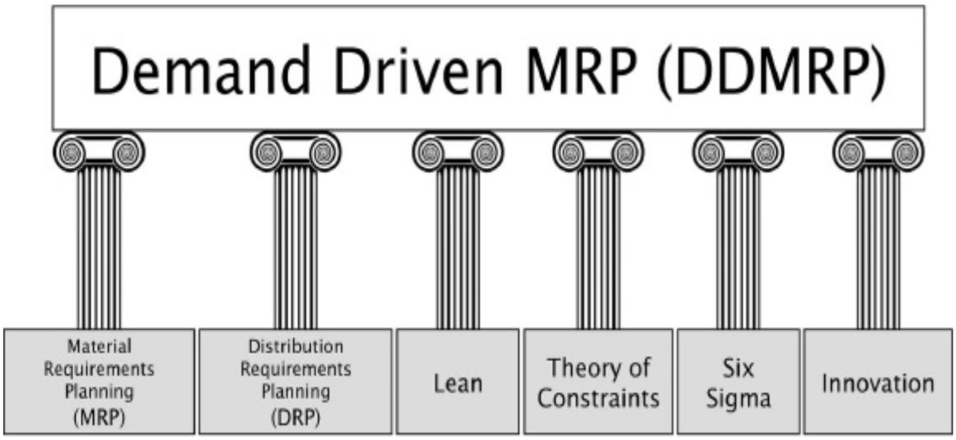


Figure 21. The Methodological foundation of DDMRP /1/.

The reason why DDMRP is invented is to control the conventional MRP's weak performance in new market circumstances, these subjects are introduced in chapter 2.3 Conventional MRP weaknesses in the New Normal, DDMRP is invented to reduce expenses, increase performance of inventory and promote & protect the flow in complex & dynamic environments and in the end, improve Return On Investment. DDMRP is formal multi-echelon planning and execution method to promote and protect the flow of relevant information and materials through the establishment and management of strategically placed decoupling point stock buffers. Decoupling is about:

"*creating independence between supply and use of material. Commonly denotes providing inventory between operations so that fluctuations in the production rate of supplying operation do not constrain production of use rates of the next operation*" /5/.

As talking about decoupling point buffers or just simply buffers it means quantities of inventory or stock that are designed to decouple demand from supply. Buffers are amounts of inventory that will provide and secure reliable availability to the consumers of the stock, while at the time allowing for the accumulation of demand orders, creating more stable, efficient and realistic supply signal to suppliers of the stock, see figure 22.

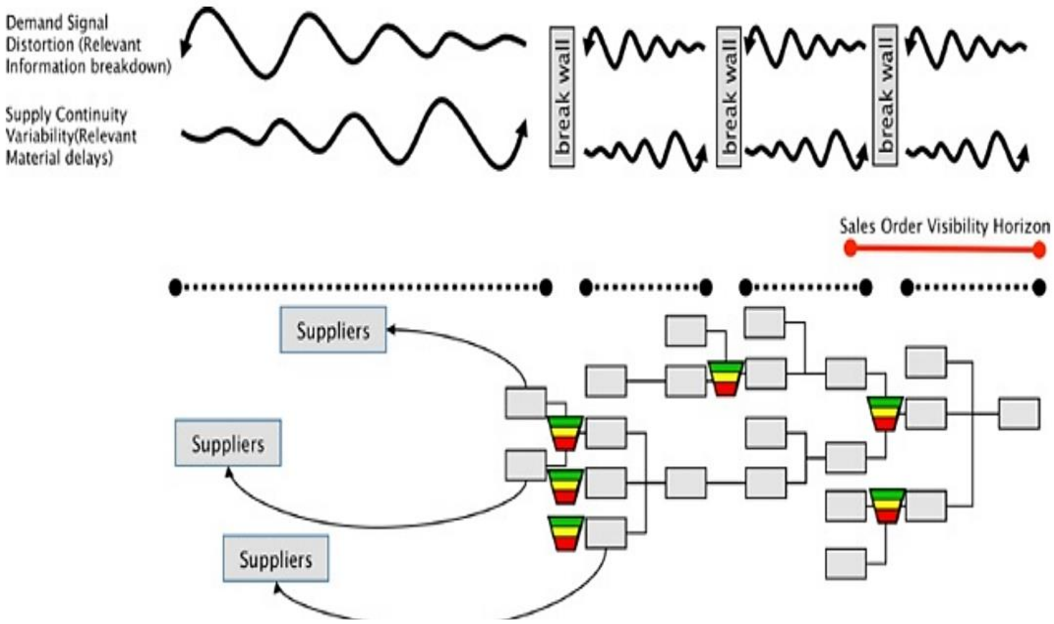


Figure 22. Demand signal distortions & Supply variability handled with Decoupling points in the system /1/.

Figure 22 shows that placing decoupling point inside the sales order visibility horizon will allow accurate demand input to the system. Decoupling buffer placement has a huge impact for the lead times, decoupling supplying lead times from the consumption side of the buffer will allow compressed lead times between buffers and to the customer. The placement of decoupling point buffers creates independent planning and execution horizons, demand and supply variability accumulations are stopped at those points. Becoming Demand Driven is a shift from centrality of supply and cost- based operational methods to a centrality of actual demand and flow-based methods, in other words from push and promote method to **position, protect**

and pull method. DDMRP has five sequential components that relate to position, protect and pull method. Initial and evolving configuration of DDMRP model are defined in first three components and actual operational aspects of DDMRP system, Planning and Execution in fourth and fifth components, see figure 23.

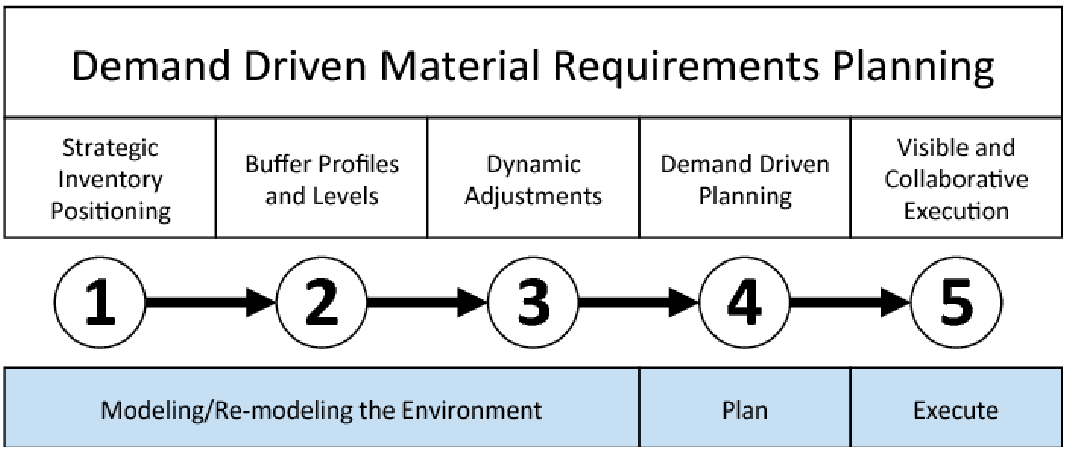


Figure 23. The five components of DDMRP /1/.

2.4.1 Strategic Inventory Positioning

The first component of DDRMP is to determine where decoupling points and buffers should be placed. Beyondmrp.com defines this as:

"Choosing the most appropriate locations offers opportunities to solve problems of shortages and unsatisfactory inventory performance and delivery performance, with implications for expediting expenses and for plant productivity as well as for service levels and opportunities to improve or gain a competitive advantage in terms of lead time and responsiveness to customer needs"

Selection of these points is a strategic decision that can achieve reduced total inventory, compressed lead time, less distribution, reduce nervousness in the system, increase stability, increase agility and protection of the performance of critical resources. DDMRP by Ptak and Smith explains six key positioning factors of Strategic Inventory Positioning:

1. **Customer Tolerance time**

The time that typical customer is willing to wait before seeking an alternative source. Customer tolerance time can be also referred to demand lead time. Determining this lead time often takes involvement of sales and customer services.

2. **Market Potential Lead Time**

The lead time that will enable company to raise the price of a product or to win business they otherwise couldn't. Determining this lead time often takes involvement of sales and customer services.

3. **Sales Order Visibility**

The time frame in which sales orders or actual dependent demand comes aware. Longer visibility to sales orders, the better capability of environment to see potential spikes and derive relevant demand signal information.

4. **External Variability**

Both Demand and Supply variability are considered for external variability.

Variable rate of Demand

The potential spikes and swings in demand that could have effect resources. Variety can be calculated though standard deviation, mean absolute deviation or variance of forecast errors and if data required for the mathematical method do not exist, companies can also use following factors:

- High-Demand variability. Products and parts that are subject to frequent spikes within the customer tolerance time.
- Medium-Demand variability. Products and parts that are subject to coincidental spikes within the customer tolerance time.
- Low-Demand variability. Products and parts that have little or no spike activity. The demand is stable within the customer tolerance time.

Variable rate of Supply

The severity of and potential for disruptions in sources of supply or specific suppliers. This can be related to supply continuity variability. Variable rate of supply can be calculated by examining the variance of promise dates versus actual dates. If the data required for mathematical method do not exist, companies can also use following factors:

- High Supply variability. Frequent supply disruptions
- Medium Supply variability. Coincidental supply distributions
- Low Supply variability. Reliable supply

5. Inventory Leverage and Flexibility

Locations in the supply chain or inside BOM that provide most options and the most potential for lead time compression to meet the business needs. Within manufacturing these places are typically represented by key purchased materials, subassemblies and intermediate components. More expansive and complex the BOMs are, the more critical it get for the environment.

6. Critical Operation Protection

The operation areas where disruptions can have effect limited capacity or variation in quality, the points that have huge impact on total flow or velocity that a plant, resource or area can maintain or achieve. The longer and complex routing structure and dependent chain of events are, more important it is to protect identified areas.

These six factors must be applied systematically across BOM, routing structure, manufacturing facilities and supply-demand network to determine the best decoupling positions for manufactured, finished and purchased items in order to protect and promote the flow relevant information and drive ROI performance, figure 24 illustrated benefits of decoupling.

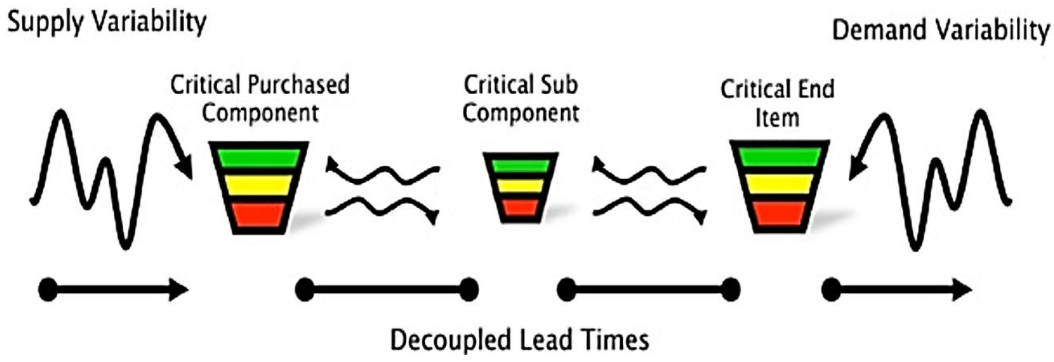


Figure 24.Illustrated Benefits of Decoupling /1/.

Applying the Position factors

The position factors are applied via viewing the products bill of material and routing structure. Routing structure means the route for operations in manufacturing a product, what operations are done, when operations are done, the sequence and standards for run & setup. The APICS describes routing as:

"Information detailing the method of manufacture of a particular item. It includes the operations to be performed, their sequence, the various work centers involved, and the standards for setup and run. In some companies, the routing also includes information on tooling, operator skill levels, inspection operations and testing requirements, and so on"

Ptak and Smith present example of applying positions criteria; Products FPE is manufactured from component 101 which is manufactured from purchased items 204P & 205P. Product FPF has third purchased item 102P, combining component 101 & item 102P, products FPF is created, see figure 25.

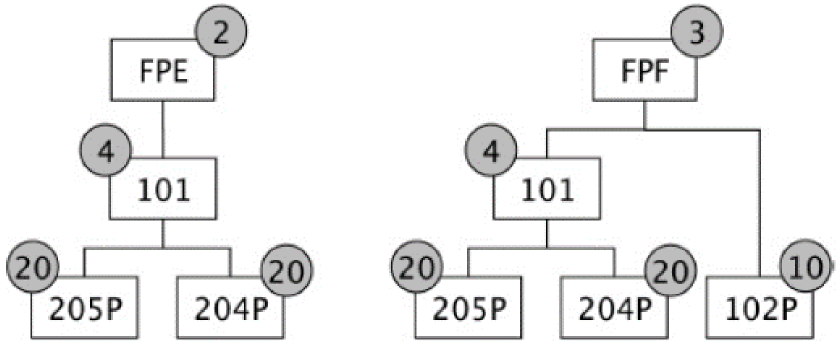


Figure 25.BOM for FPE and FPF with lead times /1/.

List 1 shows lead times for Product, component & items.

Table 1. Entire BOM lead times list

Product, components, items	Manufacturing Lead time	Purchase Lead time	Cumulative Lead time
FPE	2		26
101	4		
205P		20	
204P		20	
FPF	3		27
101	4		
205P		20	
204P		20	
102P		10	

Item 205P needs to go through a series of resources A→B→C→D & 204P series of B→C→E→F, before they are combined in resource **Z** to produce component 101. Same amount of items 205P & 204P is needed to produce component 101 in the same time. Item 101 is needed to go through of resources S→T until it becomes Product FPE. For product FPF in resource S, assembly 101 and item 102P are combined and then resource T. The same amount of assembly 101 and item 102P is needed to produce product FPF. FPF has lower volumes, as it is a higher-end product, but the market expects it within the same time frame as the lower-end product FPE. The product and routing structure for FPE and FPF is shown in figure 26.

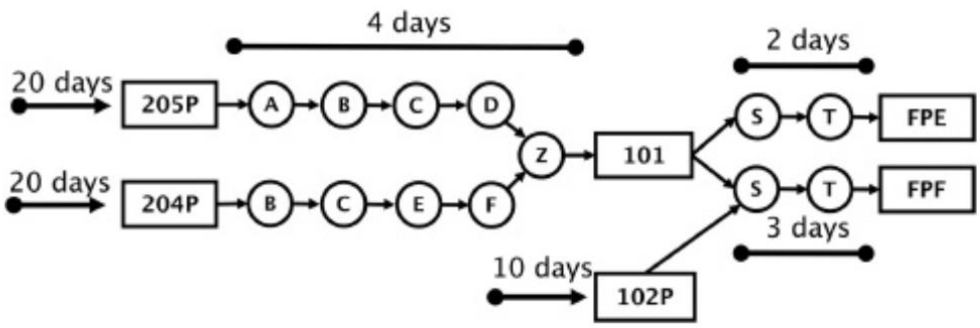


Figure 26. Product & Routing structure /1/.

Before choosing where the decoupling points must be placed in routing structure, the six key factors must be reviewed for the entire BOM. In this example these answers to the criteria is used (figure 27).

Decoupling Point Placement Criteria	Example Answers
Customer tolerance time	3 days for both FPE and FPF
Market potential lead time	FPE has quick-turn (1-day) market available
Sales order visibility horizon	3+ days for most orders
External variability	**Demand:** Large orders are typically known well in advance **Supply:** 204P and 205P have decent reliability. 102P supplier is notorious for poor delivery and quality performance
Inventory leverage and flexibility	101 is a common component for both FPE and FPF
Critical operation protection	Resource Z is an assembly operation that requires both routing paths to be complete before it begin its operation

Figure 27. Decoupling point Placement criteria & answers /1/.

- Customer Tolerance time

For a customer tolerance time of 3 days, it is recommended to place decoupling at the end of the item or 101 and 102P levels. Without placing coupling point as pointed, making the product will require forecast.

- Market potential lead time

The benefit for decoupling and stocking at FPE is the additional volume, the customer could provide growth of revenue.

- Sales order visibility horizon

For allowing the environment to pace to actual sales orders, decoupling at the finished goods or 101 and 102P would be needed. This is the best signal for demand to secure the alignment of resources to actual requirements.

- External variability

Demand variability is not a big issue but supply variety for item 102P is an issue, stocking at 102P would erase supply variety.

- Inventory leverage and flexibility

Decoupling and stocking at 101 would allow common component flow to end item as required.

- Critical operation protection

Decoupling positions 204P & 205P would provide protection to resource Z from product structure perspective. Z resource is a point where two items are combined and 101 is produced from the point. As it is a critical point the flow must be protected as much as possible.

Figure 28 presents decoupling point positions based on these factors.

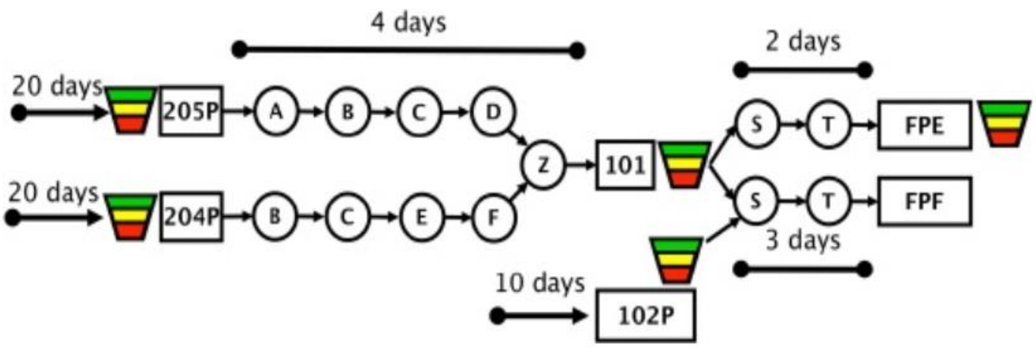


Figure 28. Decoupling positions in routing structure based on positioning factor answers /1/.

Benefits and key element of decoupling in this example includes:

- FPE stock position allows quick-turn business to be satisfied. Stock position allows an increase in sales revenue.
- Due the short lead time from decoupling in 101, FPE stock position is minimized.
- FPF can move to an assemble to order strategy as the lead time and customer tolerance time is met by other. This lead time can be achieved by three factors.
    1. 101 & 102P are available as needed, lead time is controlled by decoupling points
    2. Demand variety is not problem, large orders are known typically in advance.
    3. Buffer at FPE minimizes capacity accumulation in resources S & T. This gains availability to achieve three-day lead time for FPF.
- Decoupling points at 204P & 205P allow variability of suppliers to be isolated from concurrent manufacturing process in front of resource Z.

A New form of Lead Time: Decoupled Lead Time (DLT)

A new form of lead time is emerging with the use of decoupling points, which must be understood and calculated in order to:

- Find high-value inventory leverage point for decoupling
- Set decoupling point buffers levels properly
- Determine realistic due dates when needed
- Compress lead times to required ranges

Decoupled lead time assumes availability of the component on parent order release at decoupling points. DLT can be defined as:

"The longest cumulative coupled lead time chain in a manufactured item's product structure. It is a form of cumulative lead time but is limited and defined by the placement of decoupling points within a product structure" /1/

Decoupled lead time is calculated by summing all the purchasing and manufacturing lead times in the chain. DLT always includes the manufacturing lead time of the parent. Any parent item that have at least one decoupled component have always longer DLT than its MLT.

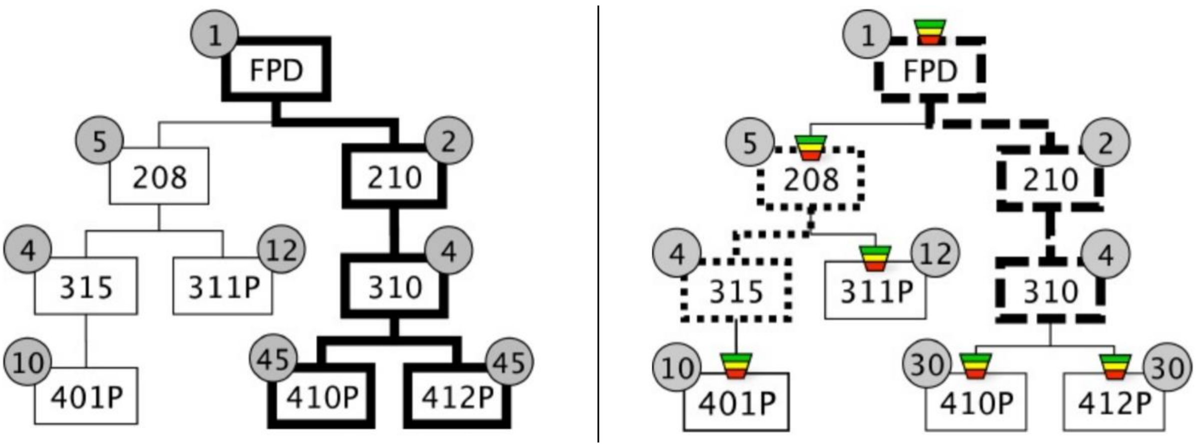


Figure 29. Product FPD's Cumulative Lead Time versus Decoupling Lead Time /1/.

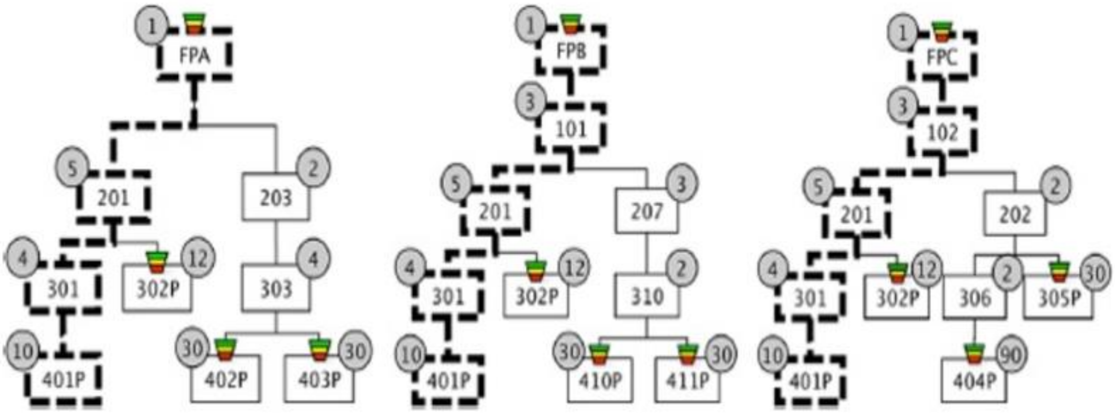
Figure 29 shows product FPD's CLT (on the left) versus DLT (on the right). When using decoupling points on path connecting FPD and 401P (dashed) as shown in the figure 29, lead time of 20 days (10+4+5+1) can be compressed to DLT of nine days (4+5). Decoupled lead time path connecting FPD and 310 is the bolded large-dashed. The length of the DLT chain is seven days, it is calculated by summing together FPD, 210 & 310 MLT (4+2+1=7). Lead time calculated with CLT method is 52 days (bolded on the left), assuming there are no components available upon order release. As we see from the figure 29 when decoupling points are used in FPA's product structure the immediate problem using CLT can be observed. Since components 401P, 410P, 412P, 311P, 208 are decoupled, it can be assumed that they are available upon parent order release. This fact makes use of CLT a gross overestimation of lead time. By using DLT planner can determine more realistic dates for the replenishment of a part and the inventory levels required for the decoupling point buffers.

Advanced Inventory Position Considerations

Companies can have many different products that have same parts or components, in other words, places where the BOMs overlap each other. Decoupling lead time opens doors for advanced inventory positioning analyses for environments in deeper and broader material structures and where shared components exists across structures. Finding the right additional decoupling point placement requires a tool called a Matrix Bill of Material. APICS describes a Matrix Bill of Material as:

"A chart made up from the bills of material for a number of products in the same or similar families. It is arranged in a matrix with components in columns and parents in rows (or vice versa) so that requirements for common components can be summarized conveniently"

The Matrix Bill of Material shows connections between all parents and all components in an environment. To get visibility where decoupling buffer points should be placed the matrix bill of material and the decoupling lead time must be used in combination.



	Parent items												
Component items	FPA	FPB	FPC	101	102	201	203	207	202	301	303	310	306
101		1											
102			1										
201	1			1	1								
203	1												
207				1									
202					1								
301						3							
302P						3							
303							1						
310								1					
306									1				
305P									1				
401P										3			
402P											1		
403P											1		
410P												1	
411P												1	
404P													1

Figure 30. BOMs and Initial matrix BOM for products FPA, DPB & FPC /1/.

The matrix bill of material for three products is presented in figure 30. Parent items are displayed at the top and components are displayed along the side. Notice that a component will often be both a child and a parent. The shaded cells represent parents or components that are decoupled or stocked. DDMRP book by Ptak & Smith presents an example where buffer points are addressed by using matrix bill of material and positioning factors. Figure 30 presents the current situation on products BOMs and DLT chains, bolded path in BOM presents the decoupled lead time chain. Notice that all finished goods are stored. Product FPA has DLT of 20 days, FPB has 23 days and FPC has 23 days also. All DLT chains of products end to component 401P and includes components 201, 301 & 401P. Customer tolerance time is three days to all end items. Looking at the products DLT chain it seems that it would be beneficial to place decoupling points somewhere in the current DLT chains, decoupling points cause direct compression of the lead time that can be offered to the market. Non-stocked parts compression of lead time must be evaluated beside the customer tolerance time and market potential lead times. Positioning strategy must meet customer tolerance times for each product while effectively leveraging and minimizing inventory investment. Placing decoupling point to component 201 for all end products will decrease DLT to 9 days on FPA, 9 day on FPD and 8 days on FPC. New DLT chain shown in figure 31 with strong bolded path. When placing decoupling point on 201, demand of 201 component is secured to end-product or to parent item, see figure 31.

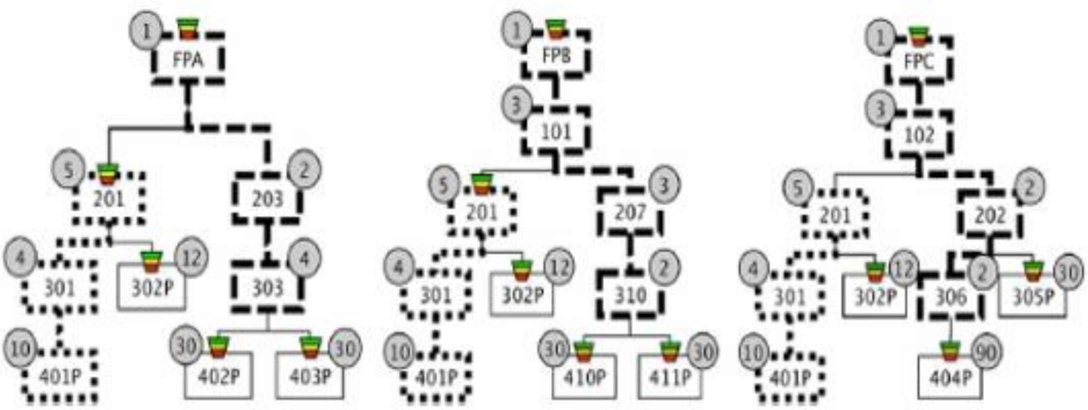
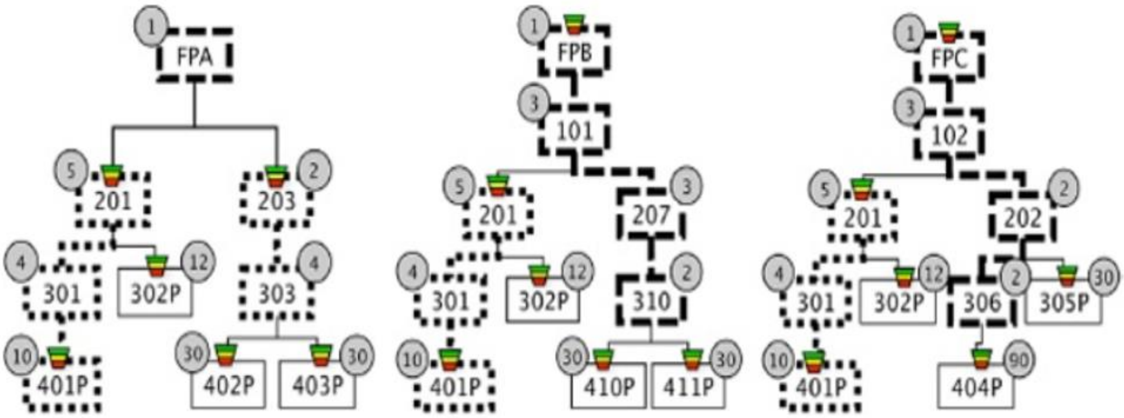


Figure 31. Component 201 Decoupled /1/.

Decoupling at 401P seems good because it will decouple external variability from the environment and path 201 - 401P lead time of 19 will drop to 9 days. Considering is it possible to compress DLT to that point that there is no inventory needed for finished goods? It is possible when placing decoupling point to parent items child item, in this case decoupling point is placed on 203 component in FPA's BOM. This allows product FPA to have a one day lead time and potentially would be able to move FPA to assemble-to-order situation (Figure 32), this allows the company to stock common components and let them flow to required parents as needed.



		Parent items												
		FPA	FPB	FPC	101	102	201	203	207	202	301	303	310	306
Component items	101		1											
	102			1										
	201	1			1	1								
	203	1												
	207				1									
	202					1								
	301						3							
	302P						3							
	303							1						
	310								1					
	306									1				
	305P									1				
	401P										3			
	402P											1		
	403P											1		
	410P												1	
	411P												1	
	404P													1

Figure 32. New Decoupled BOMs & Matrix BOM /1/.

Figure 33 shows graphically the demand signal distortions and supply variability handled with decoupling points in product FPA's BOM.

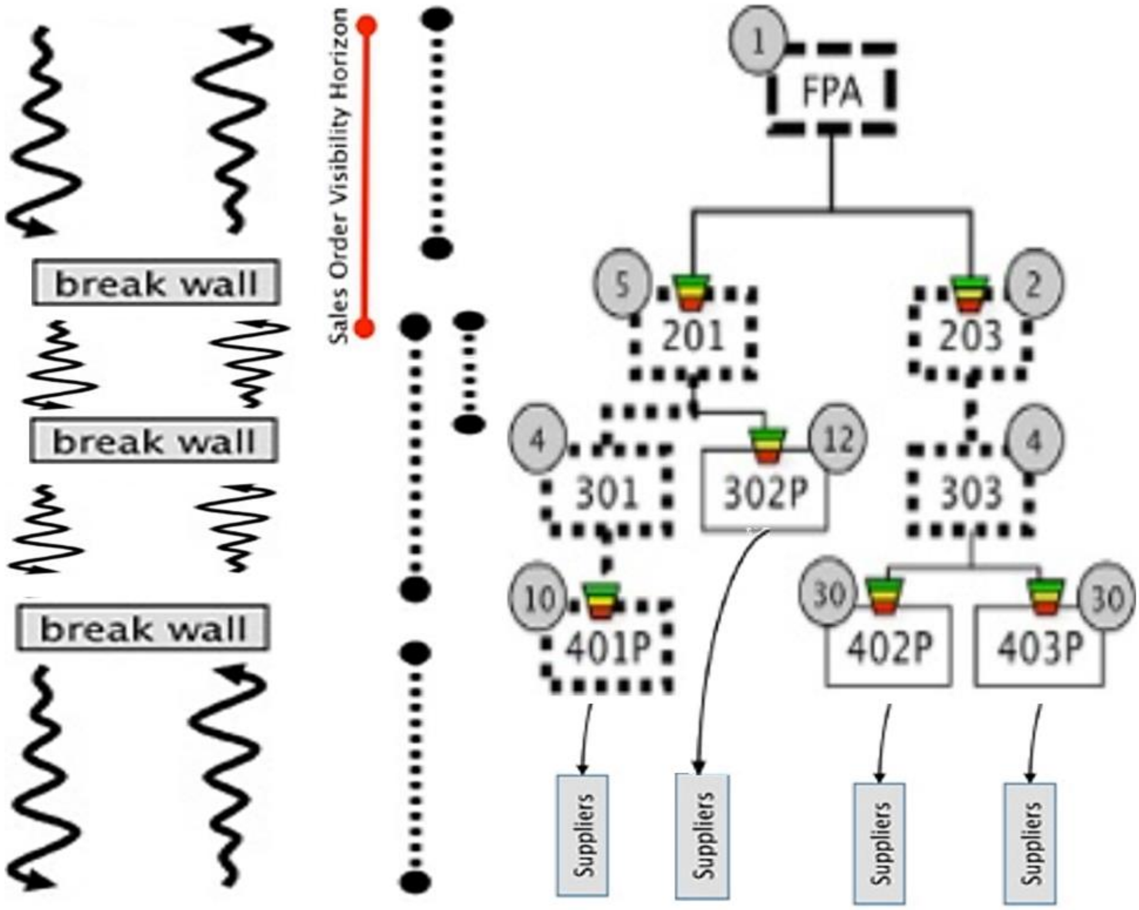


Figure 33. Demand signal distortions & supply variability handled with Decoupling points in product FPA’s BOM.

Chapter 2.4 Summary

This chapter summaries exploration of the first component of DDMRP – inventory positioning in manufacturing environment. As this thesis covers decoupling of product bill of material and routing structure, the DDMRP book also describes decoupling of distribution network aspects. I highly recommend Wärtsilä to check and study the benefits of decoupling the manufacturing environment & distribution networks, as Wärtsilä is developing and building the future eco-system. As the eco-systems are collecting big amount of various data (*Big Data*) and computers use and learn from it (*Machine learning*), I see the Demand Driven aspects highly meeting eco-system aspects and these two should be viewed together to get the best future solution.

2.4.2 Strategic Buffers

Second component of DDMRP is sizing considerations of strategic inventory buffers, how to calculate the optimal range where inventory is performing well when considering part stock keeping unit (SKU), material flow, inventory expenses and resource allocation, and in the end performance of return on investment. There is a range where inventory is an asset and range where it is a liability. Inventory has two points that have huge impact on material flow, point A where there is too little and B where there is too much. Between point A & B is range where is optimal range and warning ranges on both sides of optimal range. These warning ranges acts as indicator to SKU optimal range when either stock quantity increases or decreases too much. In this chapter we go through how to calculate the size of the necessary protection at decoupling points (figure 34).

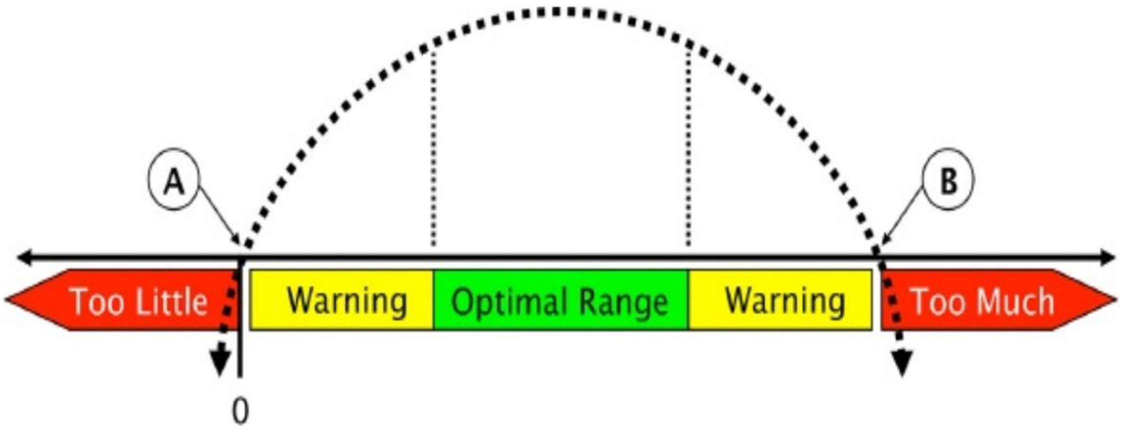


Figure 34. The inventory value loss function illustrated. /1/

Buffer Profiles

Buffer Profiles are families of parts for which it makes sense to plan a set of rules, guidelines and procedures which can be applied the same way to all members of given Buffer Profile. Buffer Profiles allow effective and practical management of massive quantities of strategically decoupled parts, see figure 35.

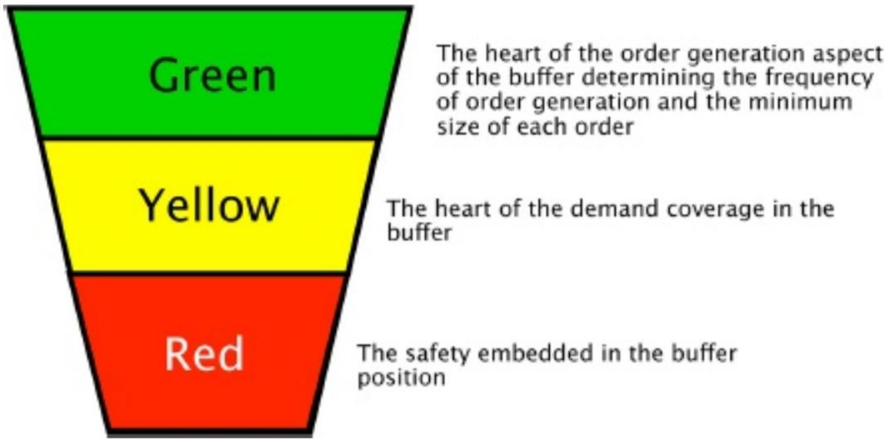


Figure 35. Buffer Zones and Purposes /1/.

The familiar connections are allocated based on three specific factors:

Factor 1: Item Type

Item grouping is determined by classifying whether is the item manufactured, purchased or distributed. Item types are marked as first letter of item type later in this text. For example, M is for Manufacturing.

Factor 2: Lead Time

Lead time has three categories: short, medium and long. For manufactured or intermediate item Decoupled Lead Time is use. For purchased parts, the purchasing lead time from the part master is used. For the distributed item the transportation lead time is used. Set of item types are categorized individually by lead time and the lead time category for items can be seen (figure 36).

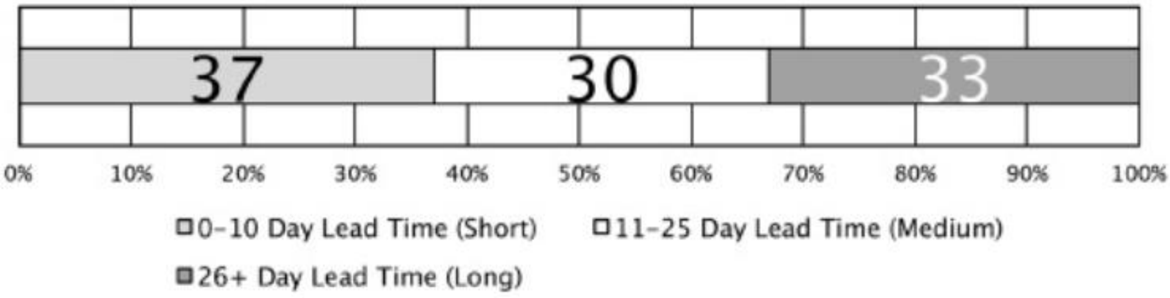


Figure 36. Company having 100 purchased parts LT categorized /1/.

The lead time category is then used to supply a "Lead Time Factor" to parts within a profile, see figure 37. DDMRP book by Ptak & Smith presents recommended Lead Time Factor list by lead time category:

Long Lead Time	20 to 40% Average Daily Usage (ADU) x Decoupled Lead Time (DLT)
Medium Lead Time	41 to 60% ADU x DLT
Short Lead Time	61 to 100% ADU x DLT

Figure 37. Lead time factor ranges /1/.

Lead time factors are later used to calculate Decoupling point Buffer Zones.

Factor 3: Demand & Supply Variability

Variability has three categories: short, medium and long. For Demand categories are segmented as:

- *"High demand variability. This part is subject to frequent spikes within the lead time*
- *Medium demand variability. This part is subject to occasional spikes within lead time*
- *Low demand variability. This part has little to no spike activity—its demand is relatively stable"* /1/.

Supply categories are segmented as:

- *"High supply variability. This part or material has frequent supply disruptions*
- *Medium supply variability. This part or material has occasional supply disruptions*
- *Low supply variability. This part or material has reliable supply"* /1/.

Lead Time and Variability categories can be shown in the same figure with a matrix sheet, see figure 38.

	Low	Medium	High	Total
Short	12	15	10	37
Medium	6	16	8	30
Long	11	14	8	33
Total	29	45	26	100

Figure 38. The Combination of lead time and variability categories /1/.

In DDMRP book Ptak & Smith (2016) presents Variability Factors by variability categories (figure 39):

High Variability	61 to 100%+ of Safety Base
Medium Variability	41 to 60% of Safety Base
Low Variability	0 to 40% of Safety Base

Figure 39. Variability category ranges /1/.

Variability Factors are later used to calculate Decoupling point Buffer Zones.

Combining all these three factors, 36 buffer profiles can be pointed, see figure 40.

Lead Time Category		Part Type: Purchased	Manufactured	Distributed	Intermediate	Variability Category
	Short	PSL	MSL	DSL	ISL	Low
		PSM	MSM	DSM	ISM	Medium
		PSH	MSH	DSH	ISH	High
	Medium	PML	MML	DML	IML	Low
		PMM	MMM	DMM	IMM	Medium
		PMH	MMH	DMH	IMH	High
	Long	PLL	MLL	DLL	ILL	Low
		PLM	MLM	DLM	ILM	Medium
		PLH	MLH	DLH	ILH	High

Figure 40. Buffer Profile combinations /1/.

For example, purchased part with long lead time and high variability is knowns as PLH.

Individual Part Attributes

Properties of numerical values specific to certain part. Many of these values are found or calculated from part master information. DDMRP uses three attributes for determining buffer levels for purchased, intermediate and manufactured items and four specific attributes for distributed items.

- **Part Average Daily Usage (ADU)**
- **Part Lead Time**
- **Part Minimum Order Quantity**
- **Part Location** (for distributed parts only!)

Decoupling point Buffers

The protection at decoupling point is called a buffer. Buffers serve three primary purposes:

- Shock absorption

    - Dampening both supply and demand variability. Reduces or eliminates the transfer of variability.
- Lead time compression
    - By decoupling supplier lead times from consumption side of the buffer lead times are compressed instantly
- Supply order generation
    - Supply order generation is determined by net flow equation, which combines all relevant demand, supply and on-hand information.

DDMRP book by Ptak & Smith 2016 presents three types of Stock Buffering methods at decoupling points: Replenished parts, Replenished override parts and Min-max parts. This thesis will focus on Replenished parts method because its predominant method used in DDMRP system. DDMRP book describes Replenished parts method as:

"*Replenished parts use strategic and dynamic decoupling point buffers. These parts are managed by a dynamic three-zone color-coded buffer system for planning and execution. The buffer levels are calculated by a combination of globally managed traits relative to the buffer profile into which the part falls and a few critical individual part attributes. These factors are adjusted within defined intervals* "

Buffer levels are determined by summing the zones that comprise them. Zones are layers in the buffer that serve specific purposes and have unique calculations.

The Green Zone

Green Zone presents supply order generation process in the buffer. It determines typical order size and average order frequency. The Green zone can be calculated by three options, <u>option that results the highest number determines the Green Zone</u>. The three calculation options are: An Imposed or Desired Minimum Order cycle, Lead Time Factor & Minimum Order Quantity.

- **Using an Imposed or Desired Minimum Order cycle**

An order cycle is the number of expected days between orders. The order cycle can be an imposed factor from the use of a product scheduling wheel, or it can be desired average number of days between orders. For both the equation is the same:

$$Avarage\ Daily\ Usage \times Desired\ or\ Imposed\ Order\ Cycle\ Days$$

- **Using Lead Time Factor**

When calculating the green zone as a percentage of usage over a full lead time the part lead time category needs to be known, is the lead time long, medium or short. The Lead Time factor is a percentage of ADU within the decoupled lead time of part. DDMRP book presents recommended lead time factor ranges, see figure 41.

Long Lead Time	20 to 40% Average Daily Usage (ADU) x Decoupled Lead Time (DLT)
Medium Lead Time	41 to 60% ADU x DLT
Short Lead Time	61 to 100% ADU x DLT

Figure 41. Lead Time factor ranges

Equation for calculating the Green Zone by using Lead Time Factor is:

$$ADU \times DLT\ \times Lead\ Time\ Factor$$

- **Using Minimum Order Quantity (MOQ)**

If the part has a minimum order quantity, it is relevant when determining green zone. The Green Zone should not never be less than minimum order quantity. The quantity of MOQ determines the volume of Green Zone.

The Yellow Zone

Yellow Zone presents inventory coverage in the buffer. The Yellow Zone is always calculated as:

$$100\%\ Avarage\ Daily\ Usage \times Decoupled\ Lead\ Time$$

The Red Zone

Red Zone presents safety in the buffer. The variability related to part or stock keeping unit will affect the Red Zone, higher the variability is, the larger Red Zone will be. The Red Zone is calculated by three sequential equations:

1. **Establish the "red base"**

Establish the red base is calculated with a same equation as Green Zone is by Lead Time Factor, the equation is:

$$ADU \times DLT \ \times Lead\ Time\ Factor$$

2. **Establish the "red safety"**

The red safety is calculated as a percentage of the red base. Item variability factor works as percentage for equation, like lead time factor for the green zone. Red safety is calculated as:

$$red\ base \times Variability\ Factor$$

3. **Total Red Zone**

Total Red Zone is calculated as summing "red base" and "red safety".

$$red\ base + red\ safety$$

Sheet (figure 42) combines all factors is used in calculating buffers are used.

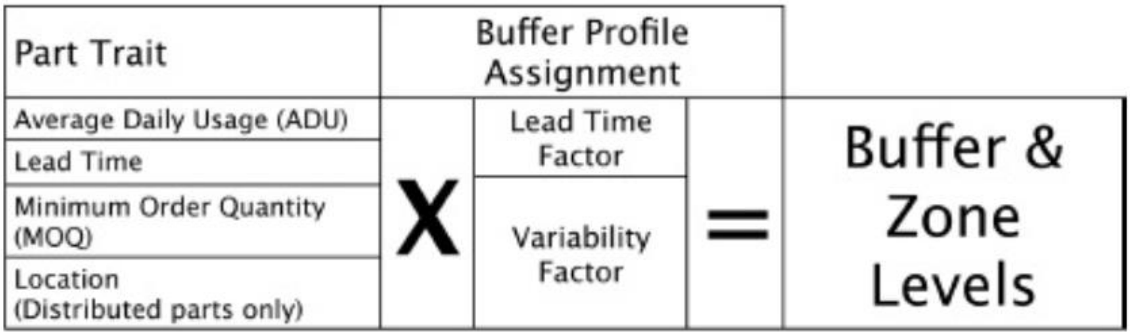


Figure 42. Buffer profile Factors /1/.

Calculating buffer & zone levels with these profile attributes (Figure 44), Lead Time factor is 50% (0,5) & Variability factor is 50% (0,5), see figure 43.

Example	
Average Daily Usage	10
Buffer Profile	M, M (.5), L (.33)
MOQ	50
Imposed or Desired Order Cycle (DOC)	7 Days
Decoupled Lead Time (DLT)	12 Days

Figure 43. Example profile attributes. /1/

When each zones are calculated and summed, the following result is achieved by the using presented attributes (Figure 44):

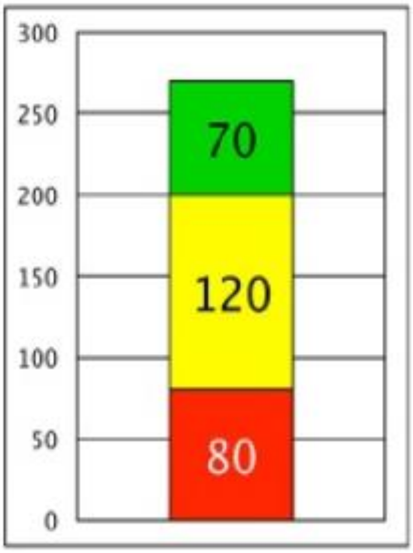


Figure 44. Example Buffer summary & levels. /1/

Calculating Replenished Override Buffers

Calculations are done using three zone system as presented above, but calculations are overridden with modified equations or user limitations. These limitations can be MOQ or order cycle. Limitations can have impact to zone capacities, but still serve the same purpose.

Calculating Min-Max Buffers

Calculating is done by only green and red zone. By not calculating yellow zone, the order generation can be modified to have more serrated shape.

Summary

The sizing of buffers requires a process of parameter setting and maintenance at both a global and individual part level. Tools and database in that environment is used from the organization’s Sales & Operations planning processes.

2.4.3 Buffer adjustments

Buffer profiles and levels must adjust and adapt to changing conditions overtime. The changes can come from part attribute changes or buffer profile changes. Demand Driven Institute Dictionary explains dynamic buffers as:

"Buffer levels that are adjusted either automatically or manually based on changes to key part traits"/8/

Recalculated adjustments

Last chapter presented three factors for all buffered parts which have impact to the buffer equations: ADU, Lead Time and MOQ. In buffer calculations, ADU & Lead Time has a higher impact because they are involved when determining each Zones, Minimum Order Quantity is only involved when determining the green zone. As the ADU is constantly updated and recalculated it is the most dynamic attribute. DDMRP book presents buffer profile calculations examples, in this example ADU is constantly changing (figure 45). Each ADU is calculated from periods of half months for six months. Other factors do not change in this particular example but later will. As we can see from figure 45, ADU effects dynamically to buffer profile levels.

Date	Red	Yellow	Green	ADU	Red Base	Red Safety	DLT	LTF	VF
1-Jan	70	100	50	10	50	20	10	0.5	0.4
15-Jan	84	150	75	15	75	30	10	0.5	0.4
1-Feb	128.8	230	115	23	115	46	10	0.5	0.4
15-Feb	212.8	380	190	38	190	76	10	0.5	0.4
1-Mar	252	450	225	45	225	90	10	0.5	0.4
15-Mar	291.2	520	260	52	260	104	10	0.5	0.4
1-Apr	308	550	275	55	275	110	10	0.5	0.4
15-Apr	324.8	580	290	58	290	116	10	0.5	0.4
1-May	302.4	540	270	54	270	108	10	0.5	0.4
15-May	313.6	560	280	56	280	112	10	0.5	0.4
1-Jun	324.8	580	290	58	290	116	10	0.5	0.4
15-Jun	296.8	530	265	53	265	106	10	0.5	0.4

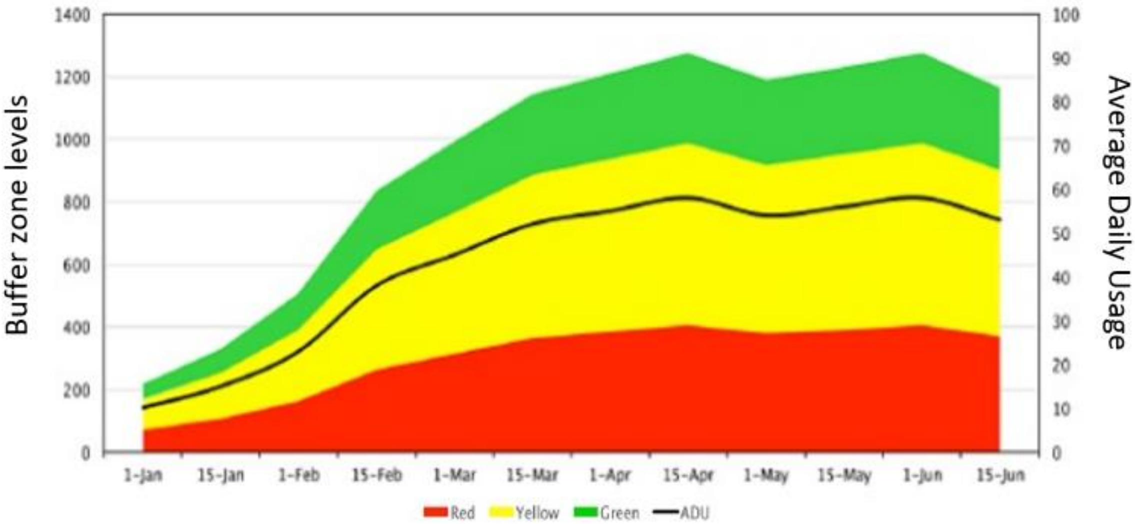


Figure 45. Part buffer adjustment over six months /1/.

Next example shows how Lead Time Changes effect to buffer profile levels (Figure 46), other factors remain the same. Shaded cells present happened changes. From 15th March the DLT changes to 5 days, remember that when DLT changes the Lead Time Factor Changes as well. In this case the impact for buffer level zones is that ADU is above buffer levels from March 15th to June 15th, this means there will be supply shortage somewhere in that period. The green and Yellow zone has a decreasing effect when DLT is compressed, when red zone is increases.

Date	Red	Yellow	Green	ADU	Red Base	Red Safety	DLT	LTF	VF	MOQ	Green (LTF)
1-Jan	70	100	50	10	50	20	10	0.5	0.4	0	50
15-Jan	84	150	75	15	75	30	10	0.5	0.4	0	75
1-Feb	128.8	230	115	23	115	46	10	0.5	0.4	0	115
15-Feb	212.8	380	190	38	190	76	10	0.5	0.4	0	190
1-Mar	252	450	225	45	225	90	10	0.5	0.4	0	225
15-Mar	291.2	260	182	52	182	72.8	5	0.7	0.4	0	182
1-Apr	308	275	192.5	55	192.5	77	5	0.7	0.4	0	192.5
15-Apr	324.8	290	203	58	203	81.2	5	0.7	0.4	0	203
1-May	302.4	270	189	54	189	75.6	5	0.7	0.4	0	189
15-May	313.6	280	196	56	196	78.4	5	0.7	0.4	0	196
1-Jun	324.8	290	203	58	203	81.2	5	0.7	0.4	0	203
15-Jun	296.8	265	185.5	53	185.5	74.2	5	0.7	0.4	0	185.5

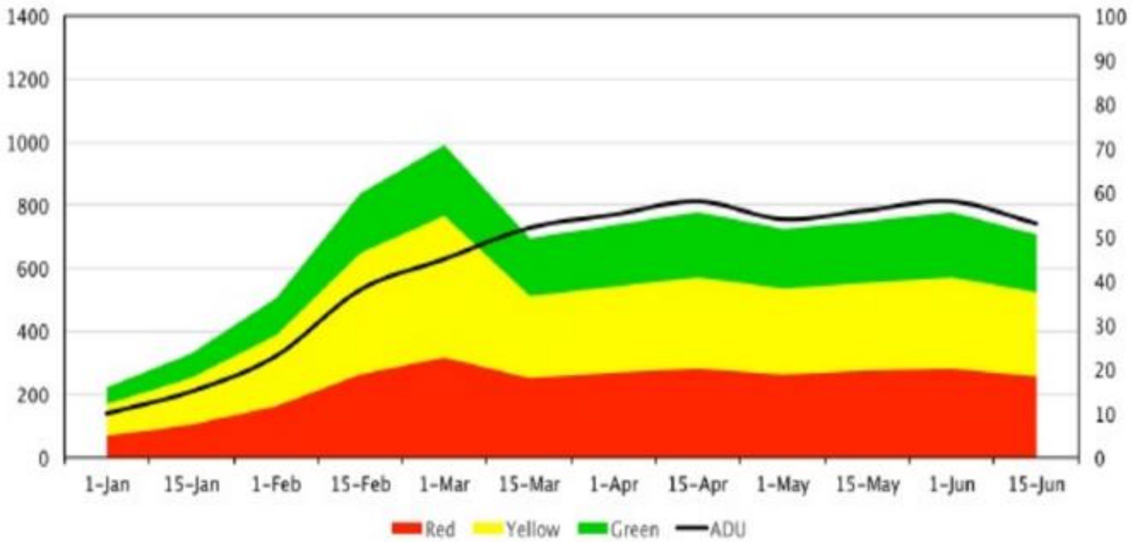


Figure 46. Lead Time compression effects /1/.

Next example shows the impact of presenting MOQ for the parts buffer profiles (Figure 47). MOQ of 400 is positioned in 15th April for the rest calculating periods. This have a big jump in the green zone, the Lead Time compression have been maintained. This has a significant impact on the amount of working capital contained in the buffer.

Date	Red	Yellow	Green	ADU	Red Base	Red Safety	DLT	LTF	VF	MOQ	Green (LTF)
1-Jan	70	100	50	10	50	20	10	0.5	0.4	0	50
15-Jan	84	150	75	15	75	30	10	0.5	0.4	0	75
1-Feb	128.8	230	115	23	115	46	10	0.5	0.4	0	115
15-Feb	212.8	380	190	38	190	76	10	0.5	0.4	0	190
1-Mar	252	450	225	45	225	90	10	0.5	0.4	0	225
15-Mar	353.6	260	182	52	130	91	5	0.5	0.7	0	182
1-Apr	374	275	192.5	55	137.5	96.25	5	0.5	0.7	0	192.5
15-Apr	394.4	290	400	58	145	101.5	5	0.5	0.7	400	203
1-May	367.2	270	400	54	135	94.5	5	0.5	0.7	400	189
15-May	380.8	280	400	56	140	98	5	0.5	0.7	400	196
1-Jun	394.4	290	400	58	145	101.5	5	0.5	0.7	400	203
15-Jun	360.4	265	400	53	132.5	92.75	5	0.5	0.7	400	185.5

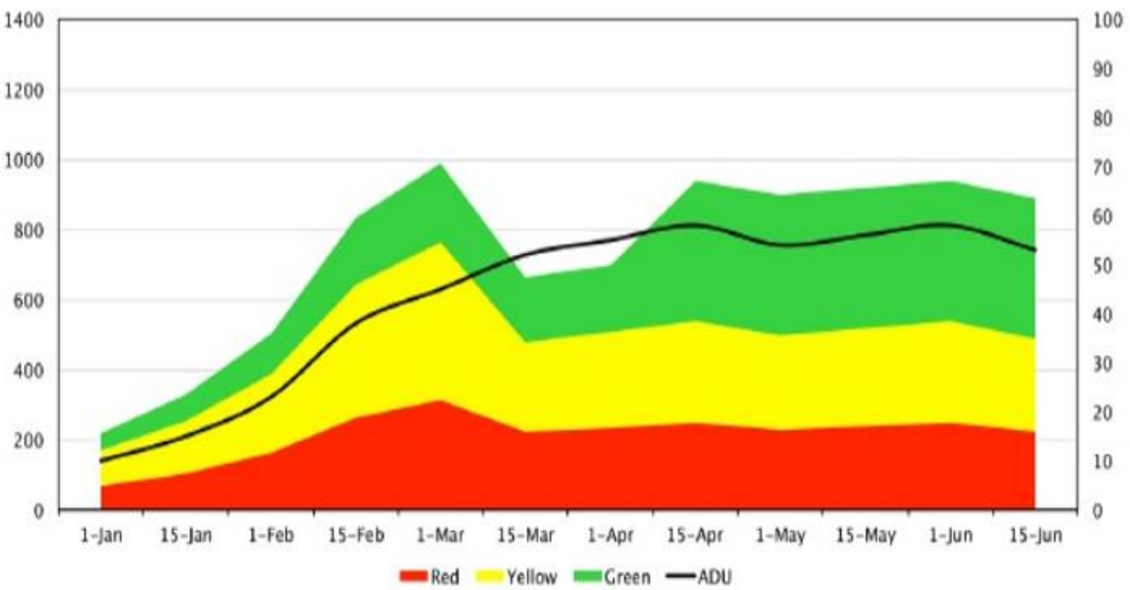


Figure 47. Part buffer profile changes with MOQ /1/.

As seen in the examples above, the buffer profile changes cause a recalculation of the buffers to all parts that are assigned to the profile.

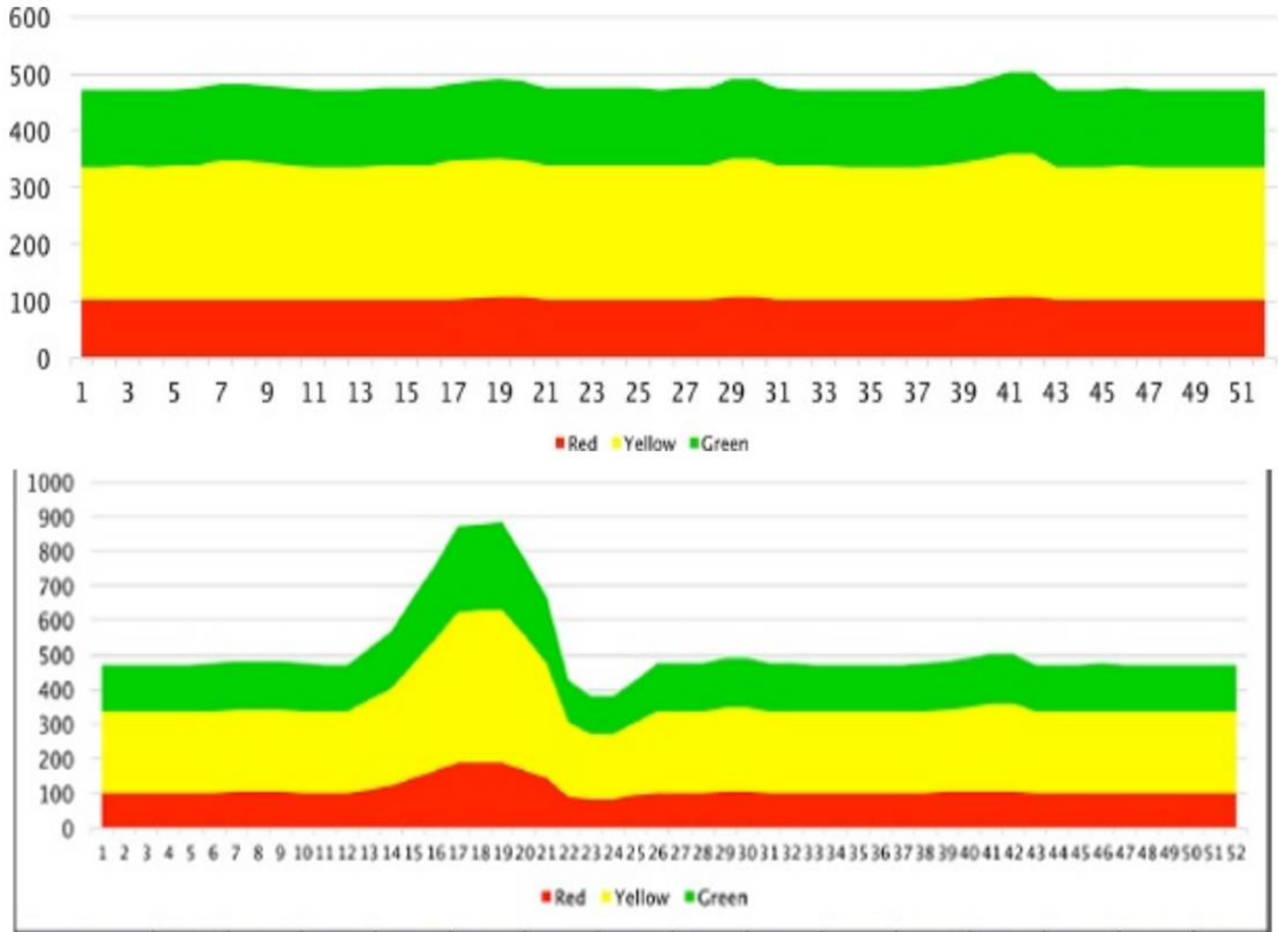
Planned Adjustment Factors

"Manipulations to the buffer equation that affect inventory positions by raising or lowering buffer levels and their corresponding zones at certain points in time. Planned adjustments are often based on certain strategic, historical, and business intelligence factors"/1/.

These manipulations attend to be confined to demand input, zonal or lead time manipulations.

- **Demand Adjustment Factor (DAF)**

DAF is manipulation to the demand input, Average Daily Usage for a specific time period. The manipulation is done based on historically proven or planned position based on approved business case or as reaction to changes in demand in short period time. DAF is designed to absorb variability. The demand Adjustment Factor is a percent multiplier for ADU that adjust ADU quantity for future. For example, a part with no demand adjustment and a part with adjusted demand (figure 48). DAF should be used when the variability seems to increase highly and overwhelm the buffers.



Week	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Original ADU	33.59	33.59	33.72	33.89	33.91	34.41	34.68	34.96	34.68	33.86	33.72	33.80	33.78	33.86	33.67
DAF	1.00	1.10	1.20	1.40	1.60	1.80	1.80	1.80	1.60	1.40	0.90	0.80	0.80	0.90	1.00
Adjusted ADU	33.59	36.94	40.47	47.44	54.26	61.94	62.43	62.93	55.49	47.40	30.35	27.04	27.02	30.47	33.67

Figure 48. Part with no demand adjustment & with demand adjustment /1/.

Product Introduction, Deletion and Transition

Demand Factor Adjustment is used when product is introduced, deleted or transition from an old item to a new item is planned. A simple example is when a product is introduced, linearly increasing DAF is used (0, 0.1, 0.2, 0.3 …) for the planned period (Figure 49). For deletion linearly decreasing DAF over time is used. For Transition these both these are used at the same time, when an old item is started to begin deleted the DAF is starting to decrease, the new items DAF starts to increase.

Increasing DAF is called Ramp up and Decreasing DAF is called Ramp down, see figure 50.

Week	Projected ADU	DAF	Adjusted ADU
1	2,000	0	0
2	2,000	0.1	200
3	2,000	0.2	400
4	2,000	0.3	600
5	2,000	0.4	800
6	2,000	0.5	1,000
7	2,000	0.6	1,200
8	2,000	0.7	1,400
9	2,000	0.8	1,600
10	2,000	0.9	1,800
11	2,000	1	2,000
12	2,000	1	2,000

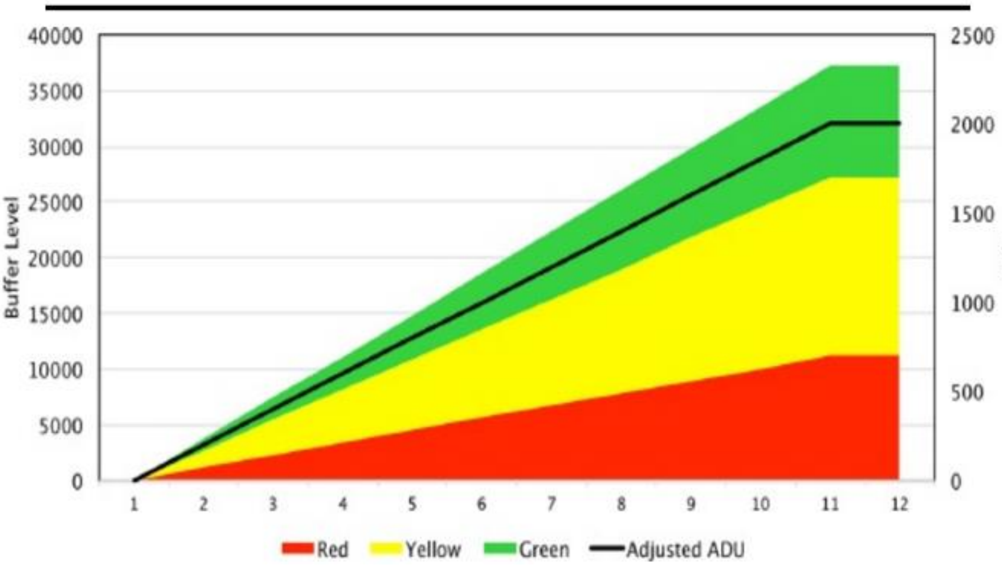
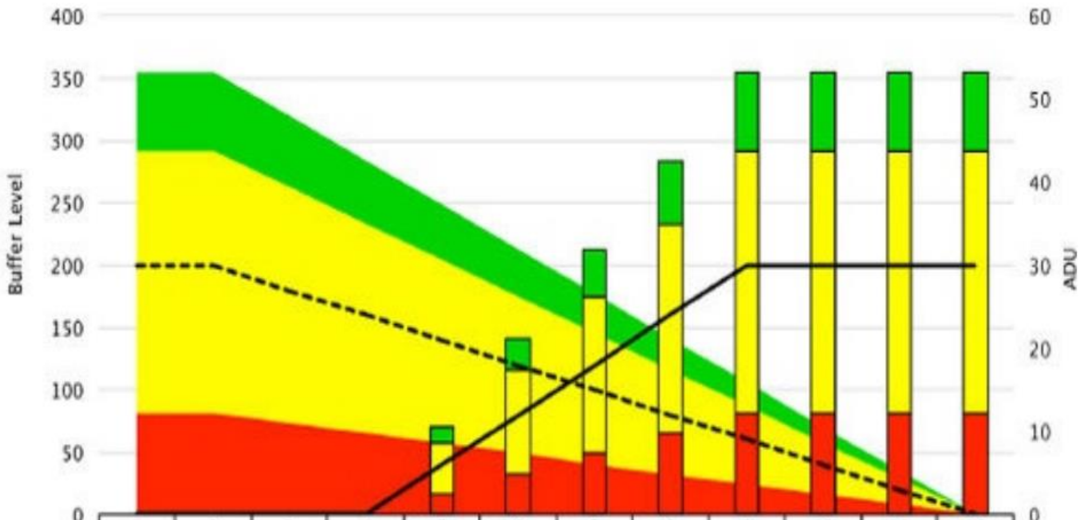


Figure 49. DAF linearly increasing, new product introduction (ramp up) /1/.



	1	2	3	4	5	6	7	8	9	10	11	12
Green (O)	63	63	56.7	50.4	44.1	37.8	31.5	25.2	18.9	12.6	6.3	0
Yellow (O)	210	210	189	168	147	126	105	84	63	42	21	0
Red (O)	81.9	81.9	73.71	65.52	57.33	49.14	40.95	32.76	24.57	16.38	8.19	0
Green (N)	0	0	0	0	12.6	25.2	37.8	50.4	63	63	63	63
Yellow (N)	0	0	0	0	42	84	126	168	210	210	210	210
Red (N)	0	0	0	0	16.38	32.76	49.14	65.52	81.9	81.9	81.9	81.9
AADU (N)	0	0	0	0	6	12	18	24	30	30	30	30
AADU (O)	30	30	27	24	21	18	15	12	9	6	3	0

Figure 50. Item transition illustrated, old items Ramp down and new items Ramp up /1/.

Applying DAF to Components and shared components

When applying DAF to components, especially for shared components between different item BOM's parent-to-component ratio need to stay the same. When demand adjustment is applied to parent item, it is necessary to apply the factor to the component buffer to properly ensure the supply to parent buffers.

- **Zone Adjustment Factor**

"Part buffer zones adjusted by a multiplicative factor to the value of the zone" /8/

Another way to adjust part buffers by multiplying with factor the wanted zone to wanted level. The part buffer zones have different purposes, so an adjustment need to be applied to the appropriate zone for appropriate reason. The green zone determines order size and frequency, multiplied with factor the order size and frequency are manipulated. Yellow Zone determines coverage in the buffer, a rate of demand in a response window. As the part having yellow zone of 7,000 (ADU of 1,000 times 7 DLT) and short-term event, market promotional for a week happens a factor of 3 can be applied to get a quantity of 21,000 yellow zone. The red zone determines safety in the buffer, manipulating the red zone a temporary change in volatility that is known or planned can be responded.

- **Lead Time Adjustment Factor**

"Applied factor that is a multiplicative to part's lead time" /8/

For example, if a lead time disruption is known the adjustment factor can be used to extend lead time and promoting the buffer zone to respond to demand.

Summary

Recalculated adjustment allows buffers to be manipulated to respond to needed demand. The biggest key attribute to change is average daily usage. Other adjustment attributes are related to known or planned events, these are called planned adjustments.

2.4.4 Demand Driven Planning

This chapter is about the method of supply order generation in DDMRP. The buffers placed on decoupling points are the heart to supply order generation in DDMRP. Decoupling points are the key points for creating, promoting, protecting and determination relevant information and materials, decoupling points create more precise and visible way to generate supply orders. The DDMRP book by Ptak & Smith they express: "*the shift to actual demand"*, which mean by that is the supply order generations from the forecast is highly incorrect, because forecasts are not accurate enough and the more the longer forecast is done the more variable and false information is. Demand and supply orders generated from forecasts cause high irrelevant costs and time loss for the company. As the forecast is not a good data source for the demand and supply order generation, thus DDMRP uses the most relevant signal; a sales order from a customer to generate supply order generations. The sales order is used with an equation called Net Flow Equation to generate the supply orders.

Net flow Equation & Supply order generation

The Net Flow Equation provides timing and quantity recommendation signal for buffer replenishment. The Net Flow Equation should be used daily on all decoupled positions. The Net Flow Equation is:

$$\begin{aligned} &On\ hand + On\ order - Qualified\ sales\ order\ demand \\ &= Net\ Flow\ Position \end{aligned}$$

Equation factor explanation:

- On-hand
  - The quantity of stock available.
- On-order
  - The quantity of stock that has been ordered but not received yet.
- Qualified sales order demand
  - The quantity of actual orders from a customer. *“Sum of sales orders past due, sales orders due today and qualified spikes”*/1/.

The Net Flow Equation answers to all equation factors; what do I have? The On-hand quantity, what will I have in the future? The On-order value, what is the demand I need to correspond now, The Sales order past due and due today, what is the relevant demand for the future? The answer is qualified order spikes.

Qualifying Order Spikes

Qualifying level and qualifying time window must be defined in order to qualify an order spike. The qualifying level is called Order Spike Threshold (**OST**) and time window is Order Spike Horizon (**OSH**). OST is can be calculated in three ways, as a “OST (50%)”, “OST (RS)” and OST (ADU). The first two are related to part buffer’s red zone and third is related to ADU. OST (50%) is calculated as: Total Red Zone times 50%, OST (RS) is just simply Red Base Value, and OST (ADU) is calculated as: ADU times 3 days. Figure 51 is to simplify the meaning of OST calculation methods. The time window, Order Spike Horizon (**OSH**) is simply calculated as: Today + DLT of the part. Figure 52 illustrates graphically OST & OSH. These are options for Qualifying Order Spikes and for planning team which method to evaluate Order Spikes.

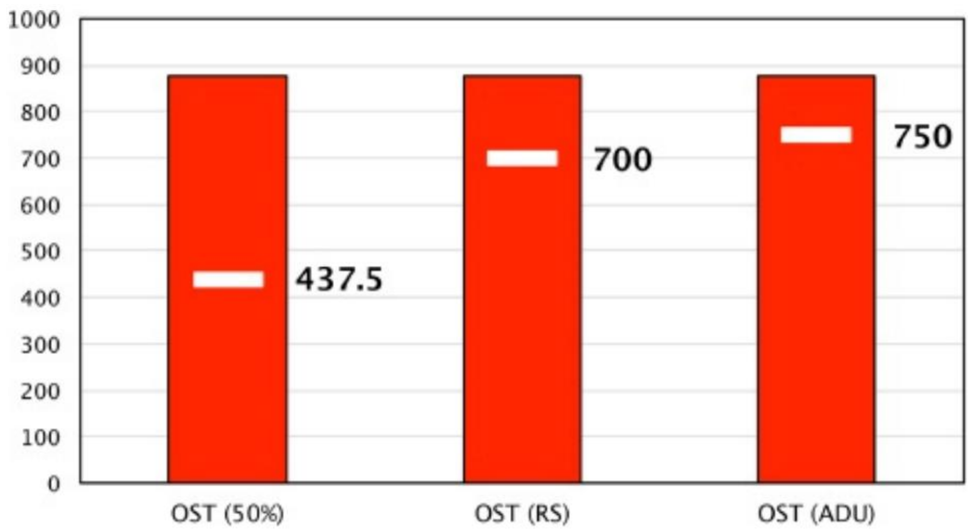


Figure 51. Three methods for setting Order Spike Threshold /1/.

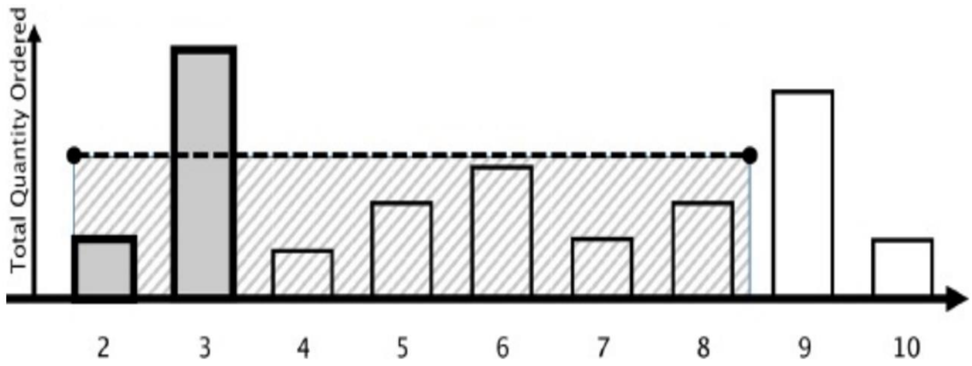


Figure 52. OST & OSH graphically illustrated /1/.

Supply Order Generation Based on Net Flow Position

Three abbreviations are presented to supply Order Generation calculations:

- TOG, Top of Green Zone
- TOY, Top of Yellow Zone
- TOR, Top of Red Zone

The Net Flow equation is dictating whether supply order will be recommended against these buffer positions. For example, if the Net Flow position is below TOY the recommended supply order quantity is TOG minus the position quantity. When Net Flow Position is below TOY, a supply order to restore the net flow position to TOG is generated. In example below, following information is used: On-hand quantity is 2652, On-order is 6233 and Qualified sales order demand is 712. From figure 53 can be seen graphically these presented acronyms and the recommended supply order can be calculated: TOY – Net Flow Position = 2715 units, see figure 53. When recommended supply order is approved, the recommended supply order is then summed to Net Flow Position, now the order recommendation has become an on-order quantity. After the new order has been accepted the order is assigned request date by parts DLT into future, in this case 10 days. When today's order has been supplied and any on-order been received, on-hand will be adjusted precisely. After On-hand inventory is adjusted it will be used to calculate tomorrow's Net Flow Equation.

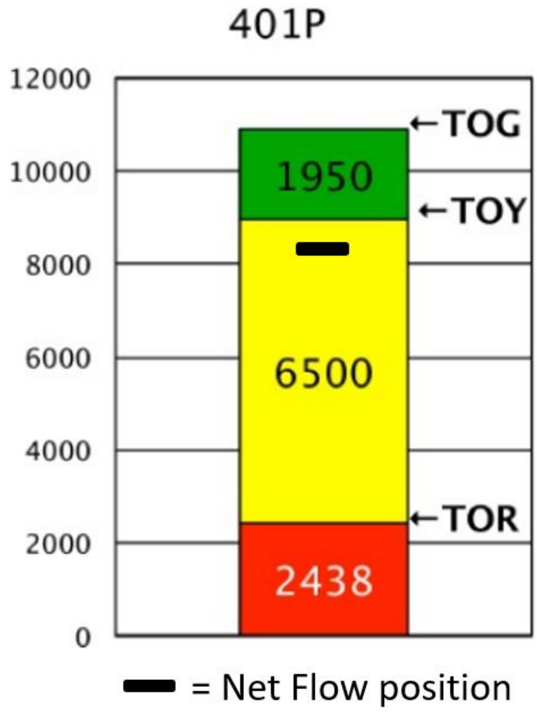


Figure 53. TOG, TOY, TOR and Net Flow Position illustrated.

Typically, the Net Flow Position is displayed as a percentage of TOG and graphically zone where it is located. The sample of planning screen in DDMRP is shown below to help with the calculations. In the planning screen, the Net Flow Position percentage has a name of Planning Priority and the box indicates the colour of the zone where Net Flow Position is situated in, see figure 54. This indicated to the planner or buyer a sense of part buffer status.

Today's Date: 15-July											
Part#	Planning Priority	On-Hand	On-Order	Qualified Demand	Net Flow Position	Order Recommendation	Request Date	Top RED	Top YELLOW	Top GREEN	Lead Time
401P	YELLOW 75.1%	2652	6233	712	8173	2715	25-Jul	2438	8938	10888	10

Figure 54. Sample planning screen in DDMRP /1/

Figure 55 shows the Net Flow Positions and Order Recommendations for multiple buffered items. With this view the planner or buyer can quickly see which buffer part needs replenishment, the lower percentage, the higher priority.

Today's Date: 15-July											
Part#	Planning Priority	On-Hand	On-Order	Qualified Demand	Net Flow Position	Order Recommendation	Request Date	Top RED	Top YELLOW	Top GREEN	Lead Time
406P	RED 19.8%	401	506	263	644	2606	4-Aug	750	2750	3250	20
403P	YELLOW 43.4%	1412	981	412	1981	2579	23-Jul	1200	3600	4560	8
402P	YELLOW 69.0%	601	753	112	1242	558	24-Jul	540	1440	1800	9
405P	YELLOW 74.0%	3400	4251	581	7070	2486	24-Jul	1756	7606	9556	9
401P	YELLOW 75.1%	2652	6233	712	8173	2715	25-Jul	2438	8938	10888	10
404P	GREEN 97.6%	1951	1560	291	3220	0		1050	2550	3300	6

Figure 55. Planning screen with multiple buffered items /1/.

Now a daily supply order generation against buffered position can be generated graphically. Figure 56 shows an example from DDMRP book that have ran 21 days. As we can see from the example, properly managed buffers can handle variability; supply problems, upticks in demand and drop in orders. Whenever the net flow position drops to TOY or below, it is raised back to Green Zone by launching supply order. Also the average on-hand quantity can be presented over the time period. As the frequency of On-hand values over the time period can be viewed, the single uniform distribution can be seen, which is opposite of bi-modal distribution (figure 57).

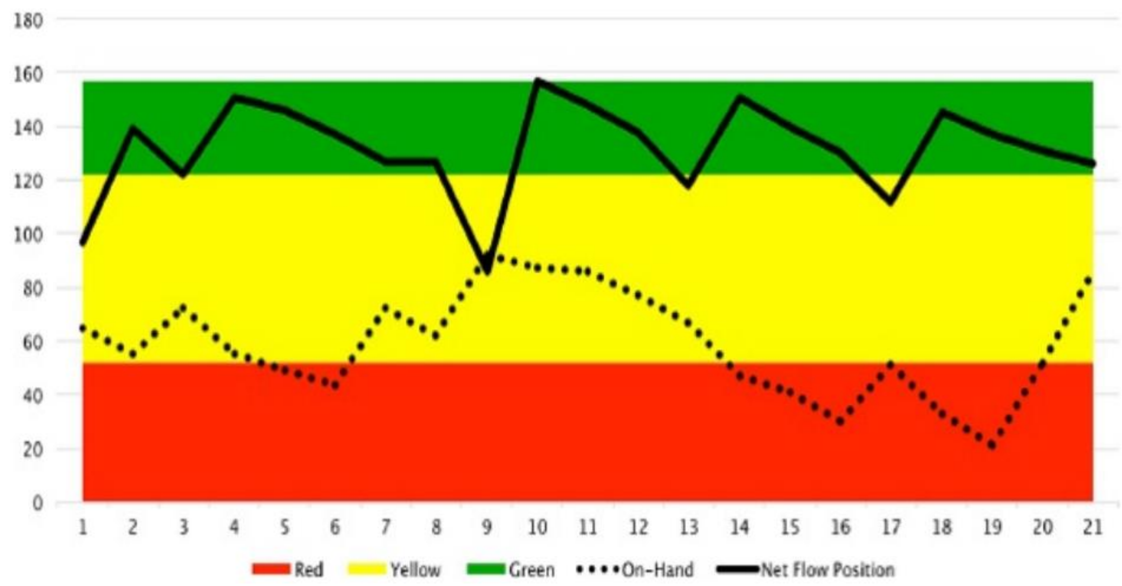
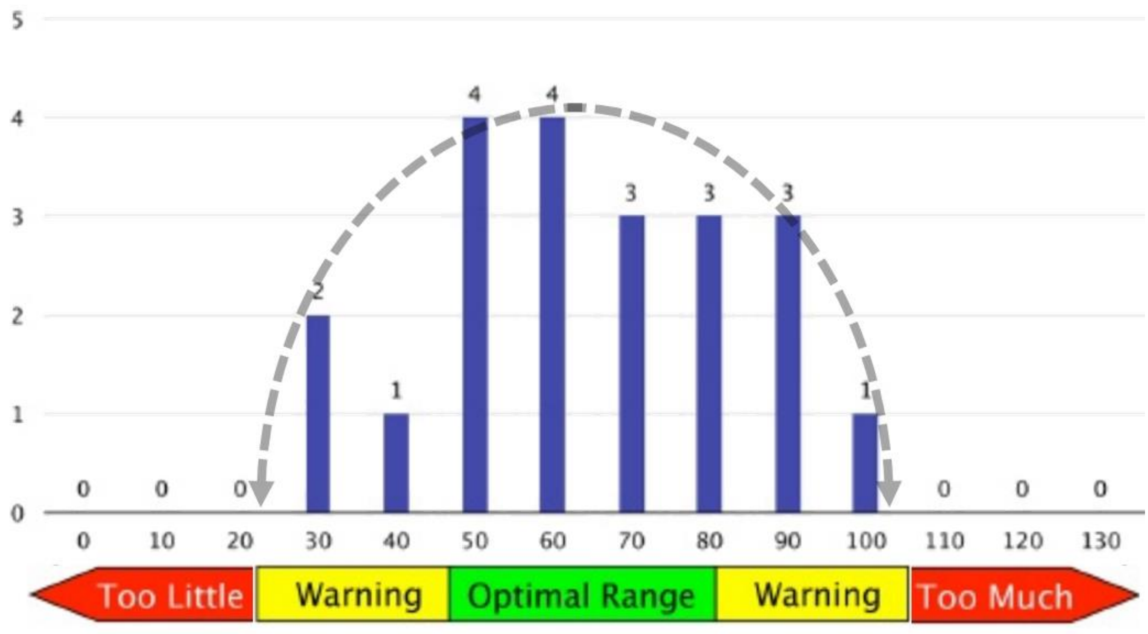


Figure 56. Example of On-hand and Net Flow Position quantities shown with part buffer over time /1/.



Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
On-Hand	65	55	72	55	49	44	72	62	92	87	86	77	67	47	41	30	51	33	21	52	86

AVG = 59.24

Figure 57. On-hand AVG and On-hand Single uniform Distribution, optimal range also illustrated.

Calculating Average On-hand inventory

As the Net Flow Equation hits the yellow zone, a supply order is recommended for a quantity that brings Net Flow Equation back to TOG. Remember the Green zone, it determines typical order size and average order frequency. For example, having green zone of 60 with 18 days lead time, times ADU of 10 times, Lead time factor of 0.33, the order frequency can be calculated by dividing green zone by ADU. This means the frequency of orders would be quantity of 60 every six days - each supply order due six days apart, see figure 58.

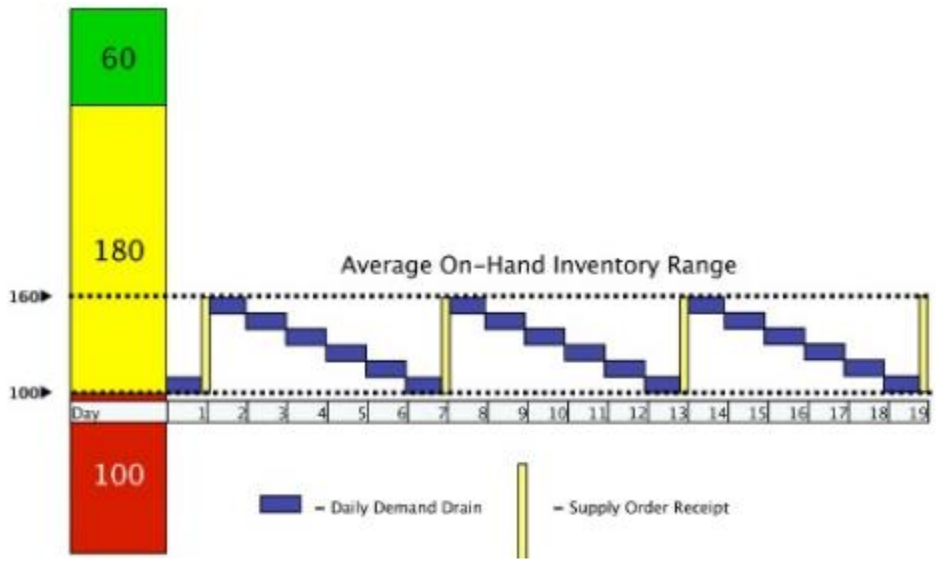


Figure 58. On hand position assuming average demand, order size and order frequency /1/.

Average on-hand range and target

Average on-hand range is two zones, the red and green. Lower limit is TOR and upper limit is TOR + TOG. With this said the inventory loss function can be calculated, as simply as: low-level warning is the Red zone, Optimal Range is Green zone and high-level warning is the Yellow zone minus the Green zone. By summing those we get this kind of graph, that presents the optimal range and low-level &

high-level warning (Figure 59). When considering target on-hand quantity, a simple calculation is made:

$$TOR + \frac{Green\ Zone}{2}$$

This simply indicates middle of optimal range.

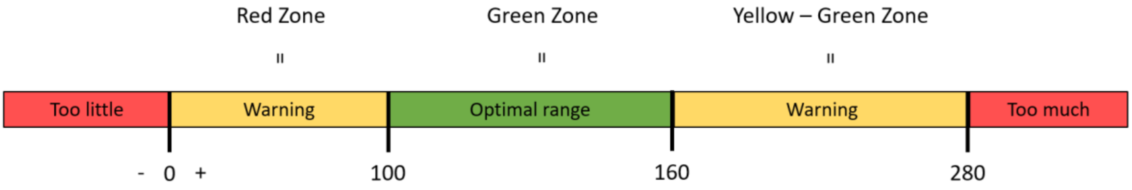


Figure 59. inventory loss function illustrated.

With inventory loss function graph combined with the average on hand graph, the performance of buffers can be presented, see figure 60.

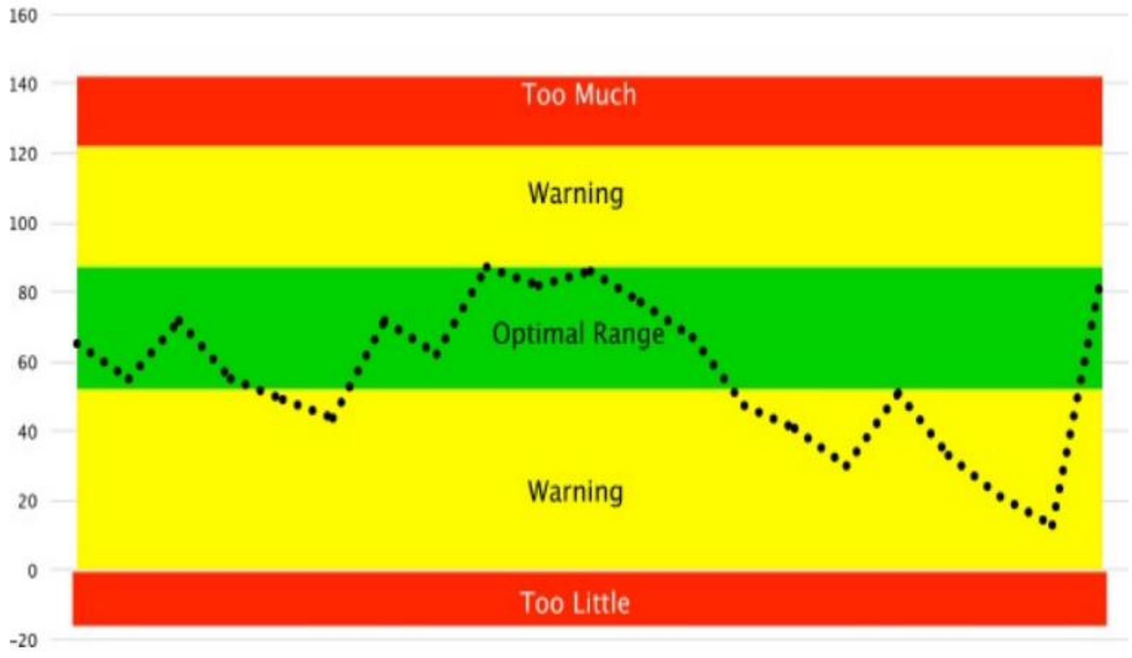


Figure 60. Inventory loss function graph with average on hand graph combined /1/.

Decoupled Explosion

As supply order is generated at high level in BOM, the explosion is stopped at lower level decoupling points, because the point is buffered. The Net Flow Equation is then calculated in that stopping point, supply order generation continues only if the positions Net Flow Equation needs resupply. With this principle the explosion begins again to lower level parts, see figure 61.

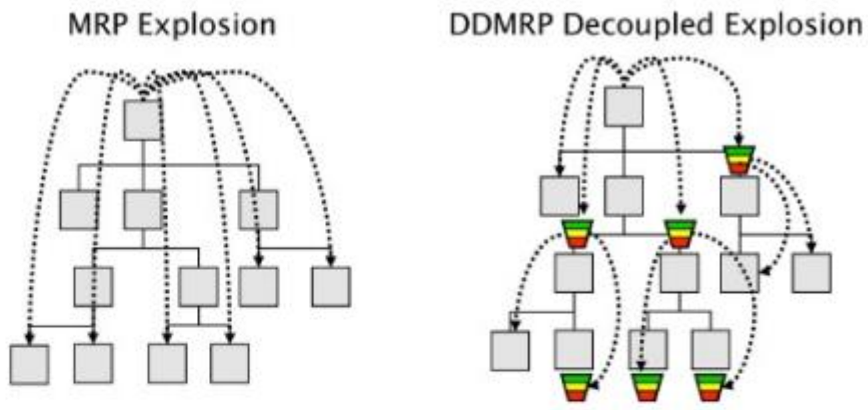


Figure 61. Difference between MRP & DDMRP Explosion.

Summary

This chapter briefly described Demand Driven Planning, how supply order is generated from qualified order and how DDMRP factors have effect on On-hand quantity over the time periods. Using Decoupling points & buffers with Net Flow Equation, supply variability and the bull whip effect can be lowered to the prudent level.

2.4.5 Demand Driven Execution

When the recommendation supply order is approved the planning ends, recommendation supply order becomes an open supply order. Execution in DDMRP is about management of open supply orders against relevant criteria. DDMRP defines two categories for the criteria that are necessary to promote and protect the flow; Buffer status and Synchronization. Four basic DDMRP execution alerts are in these two categories; Current on hand & Projected on hand alert in Buffer status alerts and Material synchronization & Lead time alert in Synchronization alerts (figure 62).

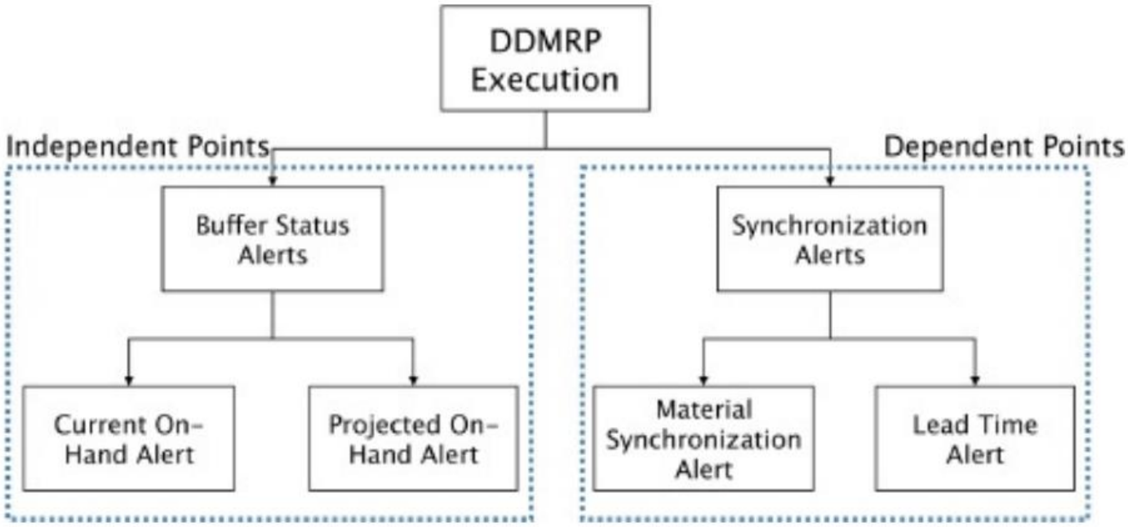


Figure 62. DDMRP Basic execution alerts /1/.

Buffer status alerts are designed to present the current and projected status of the decoupling point positions across the Demand Driven Operating Model as the Synchronization alerts are designed to present problems regarding dependencies.

Buffer Status Alerts

"The buffer status can provide a quick and intuitive way to align efforts to best protect the DDMRP model. Buffer status alerts do not use the net flow equation; they utilize on-hand values only. This separates the activities dedicated to supply order generation from the activities dedicated to open supply order management. Thus buffer status alerts represent a different perspective than DDMRP planning" /1/.

- **Current on hand Alert**

The current on hand status is monitored to show what positions need open supply, it focusses on today's on hand buffer position against the defined execution buffer status definition, see figure 63.

On-Hand Alert Manufactured Parts	
Part #	Status
FPB	RED – 20.7%
IC203	YELLOW – 53.5%
FPC	YELLOW – 99.4%

Figure 63. Sample manufacturers part's current in hand alert screen.

- **Projected On hand alert**

Projected alert is used to get visibility into future, typically one lead time ahead.

"The projected on-hand alert takes today's on-hand inventory and projects on-hand status for each future day based on the average daily usage or the quantity and timing of known demand allocations, depending on which is larger, and the quantity and timing of expected supply order receipts" /1/

Synchronization Alerts

As decoupling creates independency between materials supply and demand, the points that are not decoupled are still dependent points. By monitoring these points less variability will pass from dependent points to independent points.

- Material Synchronization Alerts

"Material synchronization alerts display supply shortfalls against known demand allocations" /1/.

The material synchronization alert presents a shortage in independent item and effected item by the shortage, parent item.

- Lead Time alerts

"An alert or warning generated by an lead time managed part. An alert will be triggered whenever the part enters a different zone in the buffer. Green is the first

alert to be encountered, followed by yellow and then red. Lead time alerts are used to prompt personnel to check up on the status of critical non-stocked parts before those parts become a synchronization issue" /1/.

Summary

This chapter presents four alerts for supply order management in DDMRP environment. These alerts are created to generate visible and collaborative execution across the Demand Driven Operation Model.

2.5 Manufacturing Plant Structures

To understand what is meant by plant structure, it is necessary to understand what they are made of. All plant structures are made of building blocks and resource-product interactions, in other words stations and flow diagrams. Station is:

"A Basic element in a manufacturing flow that defines a specific operation performed on a specific part at a specific resource" /12/

Thus, information that presents a Station are; Part, Operation and Resource identification. Stations can have multiple input and outputs, also input can be raw material and item. Line or route of stations, where raw material or part is converted by stations to end item is called product flow diagram. A flow diagram shows all parts, operations and resources identified to produce the end item in a progressive order manner. Figure 64 present a Product flow diagram; boxes illustrates Stations and triangle raw material. The figure also illustrates multiple inputs and outputs from a station.

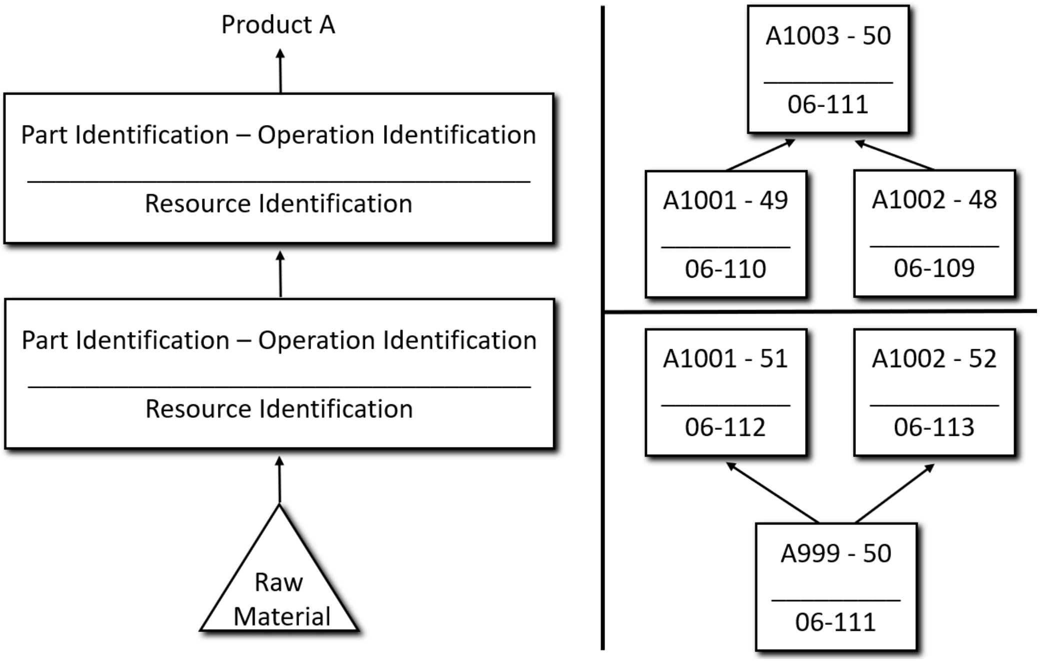


Figure 64. Product flow Diagram & Stations having multiple inputs (Upper right) and outputs (Lower right).

By these two factors the plant structure can be identified, how manufacturing plant manufactures product or products. Synchronous management book by M.M.Umble & M.L. Srikanth presents plant structure classification, V-A-T classification. Plants can be classified as V, A & T- type of plant.

2.5.1 V-Plants

"V-plants consist of those plants that convert basic raw materials or partially processed items into a variety of end items, sold either as consumer goods or as materials or components parts for other manufacturers, including assembly parts"/12/.

As from the name can be identified, V-plants consist of resource-product interactions where single product at one stage is transformed into several distinct products at the next stage. As climbing up the stages the divergence points always increases. Figure 65 illustrates typical product flow in V-plants.

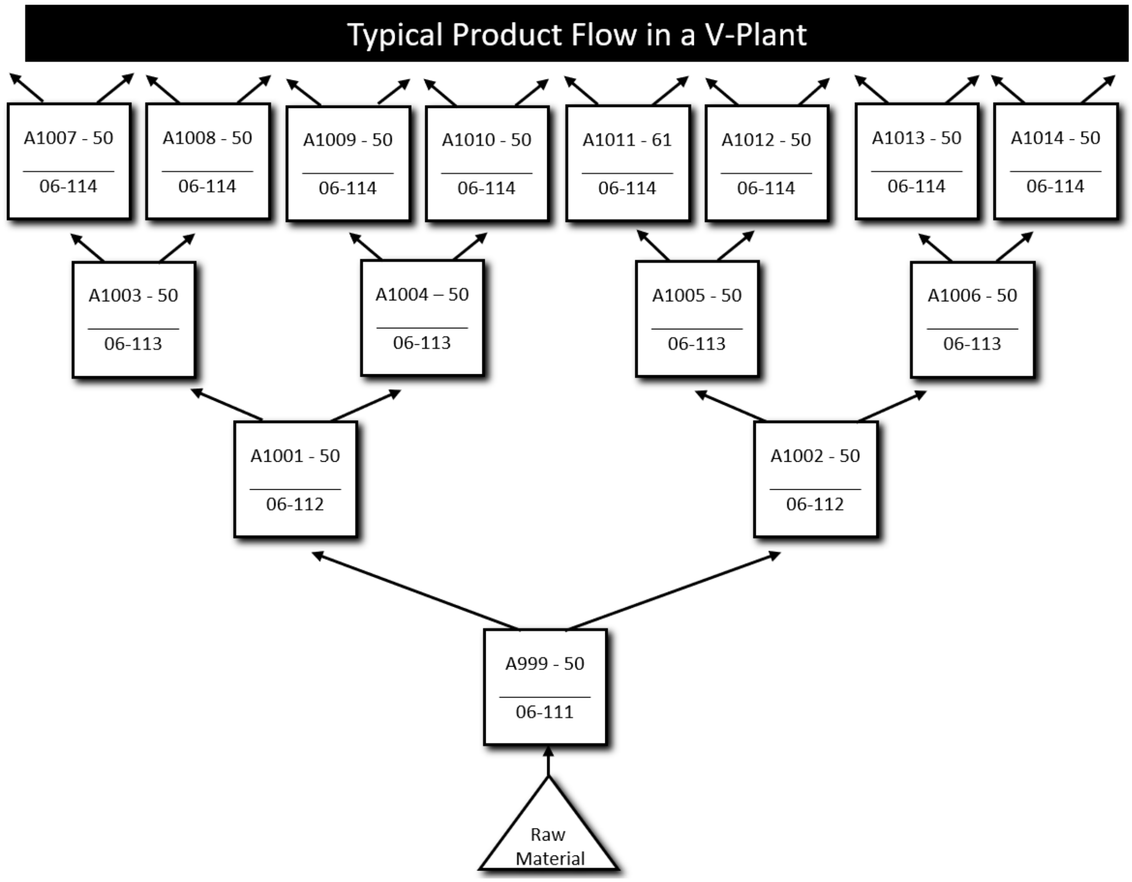


Figure 65. Typical Product flow in V-Plants.

The general characteristics of V-plant are:

1. *"The number of end items is large compared to the number of raw materials*
2. *All end items sold by the plant are produced in essentially the same way*
3. *The equipment is generally capital intensive and highly specialized"* /12/

A good example of V-plant type is steel rolling mill and textile plant, operations that are done at same level are the same, operation will change only when climbing up the diagram. One raw material is used to produce hundreds to a few thousand different end items.

The major concerns facing the V-plants are:

1. *“Finished good inventory is too large*
2. *Customer service is poor*
3. *Constant changes in demand*
4. *Responsiveness lack*
5. *Interdepartmental conflicts with manufacturing areas”*/12/

The biggest problems of V-plant may be the constant change in demand and a bottleneck operation in the system. Via having changes in demand, the customer service cannot be met. Whether not having or having a bottleneck operation in the system it has two consequences; inventory is too large that allocates a huge amount of resources or it is small to meet customer demand. These two concerns combined cause high costs and lost market share in the business.

2.5.2 A-Plants

A-plants consist of those plants that convert a variety of raw material or partially processed items into a small amount of end items. Dominant characteristic of A-plant is the resource-product interactions where two or more component parts are assembled to produce one parent item. Figure 66 graphically presents the product flow diagram for A-plants, the empty triangles presents raw material or purchased components.

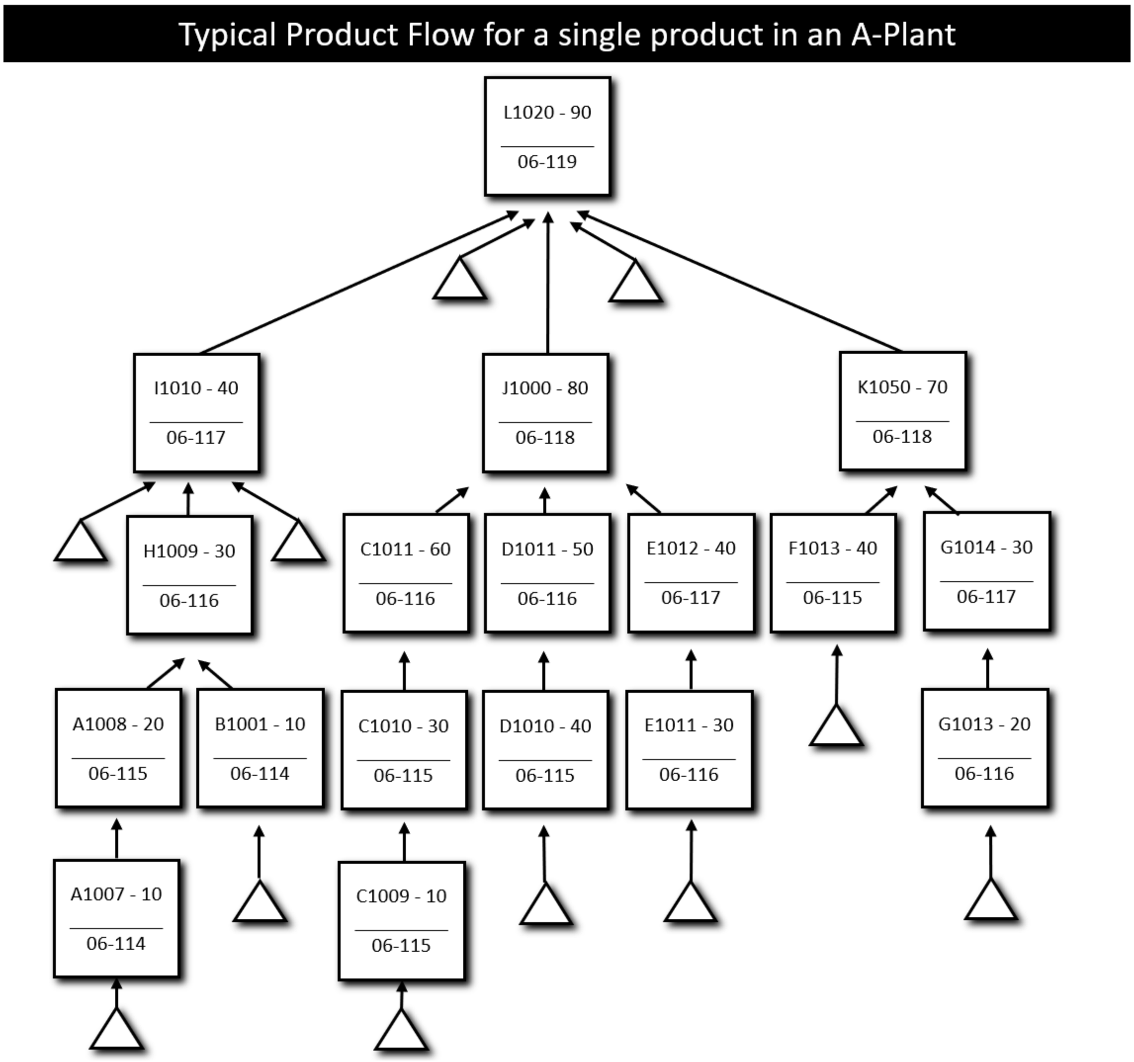


Figure 66. Product flow diagram for A-Plant.

General characteristics of A-plant are:

1. *"Assembly of large number of manufactured parts into a relatively small number of end items*
2. *The component parts are unique to specific end items*
3. *The production routings for the component parts are highly dissimilar*
4. *The machines and tools used in the manufacturing process tend to be general purpose"* /12/

A good example of A-plant is jet engine manufacturing plant. Jet engine consist of many manufactured components. Components are specifically designed to have a specific function. Producing these components have highly dissimilar production routing but has same machines and tools to produce them.

Major concerns of A-plants are:

1. *"Assembly is continually complaining of* shortages
2. *Unplanned overtime excessive*
3. *Resource utilization (not activation) is unsatisfactory*
4. *Production bottlenecks seem to wander about the plant*
5. *The entire operation appears to be out of control"* /12/

A huge factor for these concerns is A-plant characteristic 1, having to manufacture many components to assemble one at upper stage. As the end item is consist of many components that are manufactured for specific function it is needed to have them in the same time to produce the end item or parent item. As supply order is accepted the production flow start to have wave-like material flow. As the having wave-like material flow the bottlenecks tend to go with it, huge increasing cost bottleneck by bottleneck and level by level is occurred and the excessive over time start to increase.

2.5.3 T-Plants

"The critical feature of T-plants is that final products are assembled using a number of component parts, most of which are common to many different final product" /12/

This said the companies that have T-plant type often have variety of end-items, product families that have many variants according to function. Figure 67 illustrates partial product flow diagram for T-plants. As it can be seen from the figure below, T-plants have divergence point only at the point where components and purchased components are combined to get end item.

The general characteristics of T-plant are:

1. *"A number of common manufactured and/or purchased component parts are assembled together to produce the final product*
2. *The component parts are common to many different end items*
3. *The product routings for the component parts do not include divergent or assembly processes*
4. *The production routings for those component parts that require processing are usually quite dissimilar"* /12/

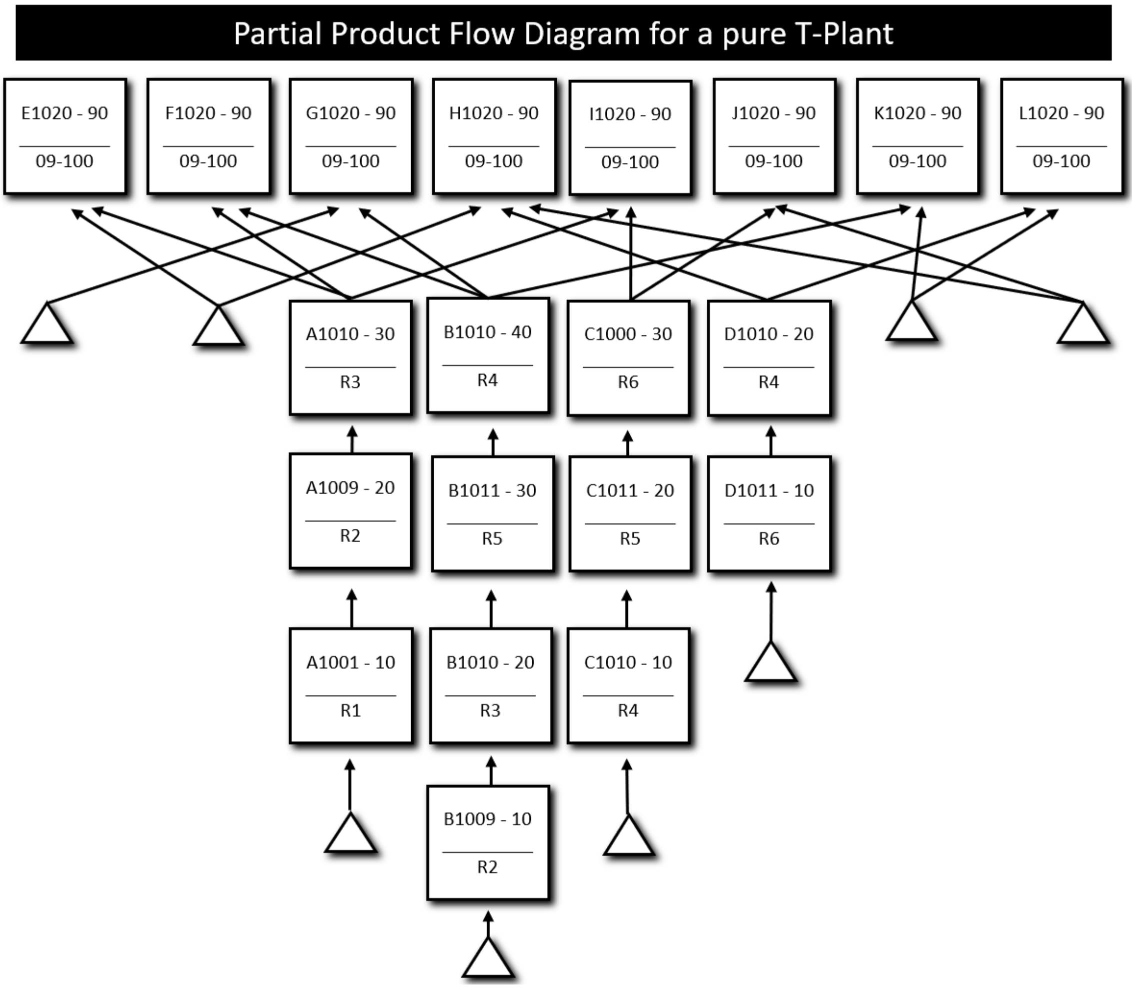


Figure 67. Illustration of Production Flow Diagram for Pure T-Plant.

A good example to T-plant type is household item manufacturing plant; producing many types of pans, many end items BOM include same components but the end products function is lightly different.

Major concerns of T-plants are:

1. *"Large finished-goods and component part inventories*
2. *Poor due date performance (30-40% early & 30-40% late)*
3. *Excessive fabrication lead times*
4. *Unsatisfactory resource utilization in fabrication*
5. *Fabrication and assembly act as separate, unsynchronized plants"* /12/

These concerns mainly occur because the characteristics of T-type of plant, having a divergence point at the stage before the end items are assembled and many shared components to many end items. It makes planning and execution of manufacturing hard. Poor due date is achieved when the half of products are produced and other half is running still, this is because the other half of end items “steals” the needed components for producing the other half. To handle this poor due date problem or “stealing”, the cost of resource allocation and utilization are extremely high. Often this problem is solved just having large inventories for finished goods and parts, cash is highly tied to inventories.

2.5.4 Combination Plants

Many plants have truly characteristics of V, A, T-plants but there are many plants that share characteristics of different plant types. Synchronous management book by M.M. Umble & M.L. Srikanth presents five basic combinations of plant types:

1. V-Base With a T-Top
2. A-Base With a T-Top
3. V-Base With an A-Top
4. V-Base With an A-Middle and a T-Top
5. A and V Side by Side, Topped off by a T

3 RESEARCH DESIGN

3.1 Research settings

The thesis is done for Wärtsilä Oyj ABP. Wärtsilä is a global leader in smart technologies and complete lifecycle solutions for the marine and energy markets. By emphasising sustainable innovation, total efficiency and data analytics, Wärtsilä maximises the environmental and economic performance of the vessels and power plants of its customers. In 2019, Wärtsilä's net sales totalled EUR 5.2 billion with approximately 19,000 employees. The company has operations in over 200 locations in more than 80 countries around the world. Wärtsilä is listed on Nasdaq Helsinki. Wärtsilä consists of two businesses: Marine Business and Energy Business. Services Business was incorporated into Marine and Energy Businesses as of January 2019. Figure 68 presents Wärtsilä key figures 2019.

Key figures

MEUR	2019
Net sales	5 170
Marine	3 330
Energy	1 840
Depreciation, amortisation and impairment	-180
Comparable operating result[1]	457
Comparable operating result[1], %	8.8
Profit before taxes	315
Earnings per share, EUR	0.37
Order intake	5 327

Figure 68. Wärtsilä key figures 2019 /16/.

Wärtsilä Marine Business is on a mission to create a Smart Marine Ecosystem – one in which the maritime industry uses only the cleanest available fuels. One where on-board power production is optimised, and routes are precision-planned to avoid navigational hazards, traffic congestion, and unexpected waiting times. Through know-how, integrated product portfolio, and full lifecycle solutions – all supported by the market's most extensive service network – Wärtsilä is committed to being the main driving force in sustainable shipping.

Wärtsilä Energy Business leads the transition towards a 100% renewable energy future. Wärtsilä helps customers unlock the value of the energy transition by optimising their energy systems and future-proofing their assets. Our offering comprises flexible power plants, energy management and storage systems, as well as lifecycle services that enable increased efficiency and guaranteed performance. Wärtsilä has delivered 72 GW of power plant capacity in 180 countries around the world. /16/

The thesis is made for Wärtsilä Finland Oy, Smart Technology Hub department. STH department is responsible for the STH Business Transformation project.

The thesis is made to explain of what kind of component is suitable for DDMRP, what is the process and data needed to indicate the suitable component in Wärtsilä Smart Technology Hub environment.

3.2 Data collection

The data collection is mostly done using physical and electronical books, but meeting face to face and via skype with senior development manager is used to discuss and gather data. Webinars by Demand Driven Institute is used to get answers for uncertainties and in-depth knowledge of DDMRP.

4 SUMMARY OF FINDINGS

4.1 Research Question 1

What kind of component is suitable for Demand Driven Material Requirement Planning in Wärtsilä Smart Technology Hub Environment?

To determine what kind of component can be suitable for demand drive MRP, you need to ask yourself:

"*Do you experience variability, volatility, uncertainty and ambiguity? Do you have too much of the wrong stuff and too little of the right stuff?"* (Figure 69).

Determining the suitable product or item includes seeking variabilities, volatilities, uncertainties and ambiguities in demand & supply and how they affect to production, inventories, service levels, costs and cash flows. Indicators for suitable item can be high excessive inventories with having high variability in demand & supply with low performance to customer demand. Identifying the product is about seeking where variabilities, production bottlenecks and high inventory assets interrupt response times, costs and ROI performance. Defining can presented as a question; Are there products where we could decrease asset usage & inventory costs, increase response time with decreasing demand & supply variabilities, increase the ROI performances or where we could promote & protect the flow.

If these criteria appear, it indicates running DDMRP is beneficial to your conditions. DDMRP is designed to reduce inventory & lead times, increase service levels and in the end increase Return on Investment performance.

If these criteria do not appear on viewed product, it is fine to run conventional material requirement planning. It is still highly important to remember and understand that market and supply chain circumstances and characteristics always change, so implementing DDMRP is not always an answer to today's problems but it can be for the future problems.

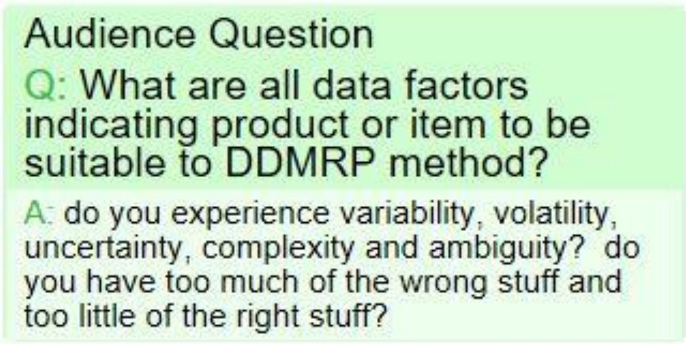


Figure 69. Question & answer from Demand Driven Institute, The Four Innovations of Demand Driven MRP Webinar 09.04.2020 /13/.

To answer more deeply to key question one, what kind of component is suitable for DDMRP in Wärtsilä STH Environment, the phase one & two and their characteristics in DDMRP must be understood. Both phases include having certain data or defining it from history or forecasts. First about phase one, Strategic Inventory Positioning. In Strategic inventory Positioning the decoupling points are placed in product(s) or parent items bill of material to provide:

"*Most appropriate locations which offers opportunities to solve problems of shortages and unsatisfactory inventory performance and delivery performance, with implications for expediting expenses and for plant productivity as well as for service levels and opportunities to improve or gain a competitive advantage in terms of lead time and responsiveness to customer needs"* /1/.

Placing these points needs data of six factors:

- Customer tolerance time
- Market potential lead time
- Sales order visibility
- External variability
    - Variable rate of demand
    - Variable rate of supply
- Inventory leverage and flexibility

- Critical operations

Customer tolerance time

Customer tolerance time indicates the time which customer is willing to wait before seeking an alternative source.

This indicated a range where one or more decoupling point(s) needs to be located at BOMs to provide a supply to customer in tolerance time or under the time. If decoupled lead time is higher than customer tolerance time the customer needs are not met. If decoupled points are not used, making the product will require forecast or some sort of anticipated signal.

Market potential lead time

The point in time where a customer is willing to pay a premium for a product or service.

Placing decoupling points so that decoupled lead time meets or be smaller than Market potential lead time can increase responsiveness, service levels and sales revenue.

Sales order visibility

The time frame in which sales orders or accrual dependent demand comes aware. Longer visibility to sales orders, the better capability of environment to see potential spikes and derive relevant demand signal information.

Placing a Decoupling point inside the sales order visibility horizon guarantees supply for demand. DDMRP method is designed so that decoupling points across BOM(s) responds to the actual demand signals with right stuff purchased and manufactured in the right time.

External variability

1. **Variable rate of demand**

The potential spikes and swings in demand that could have effect resources. Variety can be calculated though standard deviation, mean absolute deviation or variance of forecast errors and if data required for the mathematical method do not exist, companies can also use following criteria:

- High-Demand variability. Products and parts that are subject to frequent spikes within the customer tolerance time.
- Medium-Demand variability. Products and parts that are subject to coincidental spikes within the customer tolerance time.
- Low-Demand variability. Products and parts that have little or no spike activity. The demand is stable within the customer tolerance time.

2. **Variable rate of Supply**

The severity of and potential for disruptions in sources of supply or specific suppliers. The variable rate of supply can be calculated by examining the variance of promise dates versus actual dates. If the data required for the mathematical method do not exist, companies can also use following criteria:

- High Supply variability. Frequent supply disruptions
- Medium Supply variability. Coincidental supply distributions
- Low Supply variability. Reliable supply

Both demand and supply variabilities must be defined either by mathematical methods or with presented criteria to entire Products or parent items BOMs. With this the variability can be tracked and treated with decoupling point(s). Supply variability needs to be tracked and defined it impacts across the BOM, how supply variety of component or raw material will have effect when producing product. Products demand variability needs to be tracked and defined to understand the effects to supply and inventories. Defined Demand & Supply variabilities play also a big role in Strategic Buffer considerations, the defined variability is then converted to variability factor which is used to calculate buffer profile zones and levels.

Inventory Leverage and Flexibility

Locations in the supply chain or inside BOM that provide most options and the most potential for lead time compression to meet the business needs. Within manufacturing these places are typically represented by key purchased materials, subassemblies and intermediate components. More expansive and complex the BOMs are, the more critical it get for the environment.

Decoupling points should be placed product(s) BOM or matrix BOM to compress lead time much as possible. Decoupling points create compressed lead times because decoupling points are designed to create independence points between supply and use of material.

Critical operations

The operation areas where disruptions can have effect limited capacity or variation in quality, the points that have huge impact on total flow or velocity that a plant, resource or area can maintain or achieve. The longer and complex routing structure and dependent chain of events are, more important it is to protect identified areas. See figure 70.

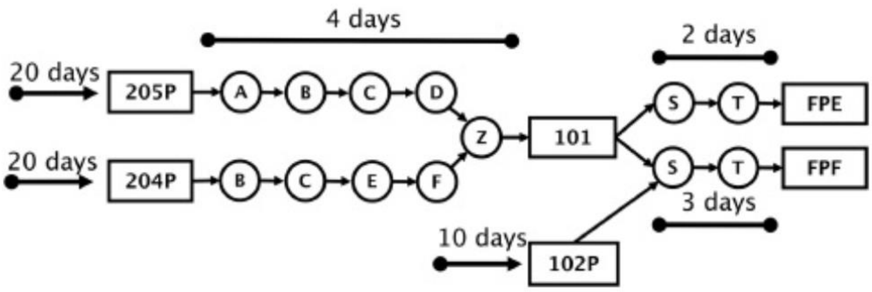


Figure 70. Product routing structure for products FPE & FPF.

Product routing structure or bill of operation must be reviewed to be able to define critical operations. Critical operations which have impact to producing the product, can be decoupled to compress lead time and respond to demand with calculated inventory buffer zones and levels.

If decoupling point(s) cannot be placed the products or components BOM, the product or component is not yet suitable for running DDMRP. If the data needed for the decoupling point positions are not yet there it does not mean that the product or component will never be suitable for DDMRP. DDMRP is a material requirement planning system that uses actual demand signal to generate supply orders. These 6 factors are used to place decoupling points where buffer zones and levels are calculated to meet customer demand as responsive as possible and with reasonable inventory. To continue DDMRP phase two; Strategic Buffer considerations, phase one must be completed in a presented way.

DDMRP Phase two, Strategic Buffers. Buffer is:

"A level of stock that is carefully sized and maintained"/1/.

Considering the buffer level & zone calculations, three data factors needs to be possible to be calculated or projected over time periods: Average Daily Usage (ADU), Minimum Order Quantity (MOQ) and Desired or imposed order cycle. These factors play role in calculating buffer profile zones and levels, calculating these buffer levels and zones are presented in chapter 2.4.2, see figure 71.

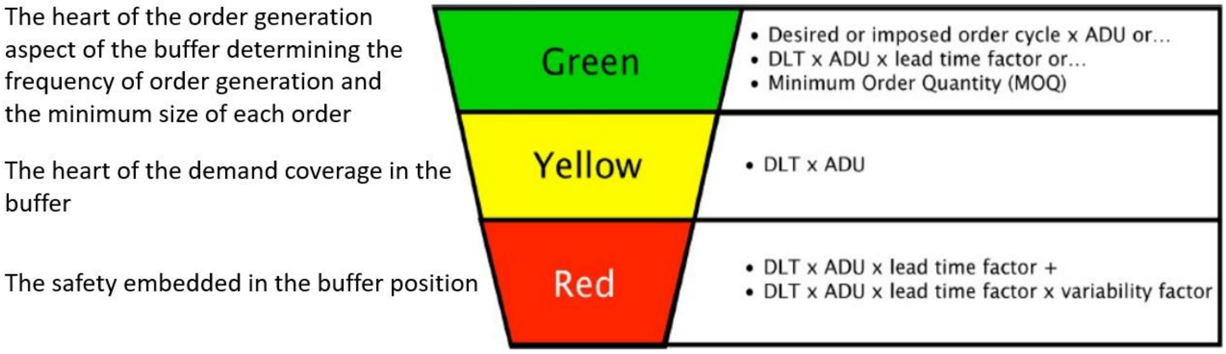


Figure 71. Buffer Equation Summary.

If company is not having these data factors the component isn't yet suitable for DDMRP. As these factors has been defined, DDMRP can be simulated and run.

To describe this in "environment" aspect, Supply chain characteristics and the plant structures must be understood.

Supply Chain Characteristics	1965	Today
Supply Chain Complexity	Low	High
Product Life Cycles	Long	Short
Customer Tolerance Times	Long	Short
Product Complexity	Low	High
Product Customization	Low	High
Product Variety	Low	High
Long Lead Time Parts	Few	Many
Forecast Accuracy	High	Low
Pressure for Leaner Inventories	Low	High
Transactional Friction	High	Low

Figure 72. Supply chain characteristics /13/.

If Wärtsilä having SC characteristics more like presents "today" in figure 72, it indicates that there would be huge benefits to implement Demand Driven MRP method. The conventional MRP method is more forecast driven, forecasts are always inaccurate. The more variability and interruption are in demand and supply, more false planning the future is. With false forecasts and forecast driven MRP method, the bimodal distribution in inventory and performance problems are very difficult to solve. To solve conventional problems and increase the ROI performance, the way of doing MRP must be changed. Most accurate data for demand is qualified demand, customer orders. DDMRP is designed to respond to all qualified demand spikes with increasing the material flow performance reasonable inventory, decreasing costs and increasing responsiveness. Conventional MRP can be used if the variability, volatility, uncertainty and ambiguity in demand & supply and inventory levels are optimal to customer demand and supply are not the things that you suffer. This means if the supply chain characteristics are like in the 1965 the conventional MRP can still be used fine. But the problem is that; do the SC characteristics always stay the same? According to chapter 2.2 The new normal, very few products have these SC circumstances, this is because when there are many competitors in the market the variabilities and responsiveness tend to increase. As this said with conventional MRP can be used with reasonable benefits in environment where SC characteristics stay the same as the figure 72 describes 1965 circumstances.

As the supply chain circumstances are tends to change, probably always to “the new normal” or how Demand Driven Institute describes today’s world as a “VUCA world” (Figure 73), I highly recommend change conventional MRP method to demand driven. As DDMRP is designed to decrease variabilities & uncertainties and increase ROI performances, it is also strategical move towards learning and controlling the future circumstances.

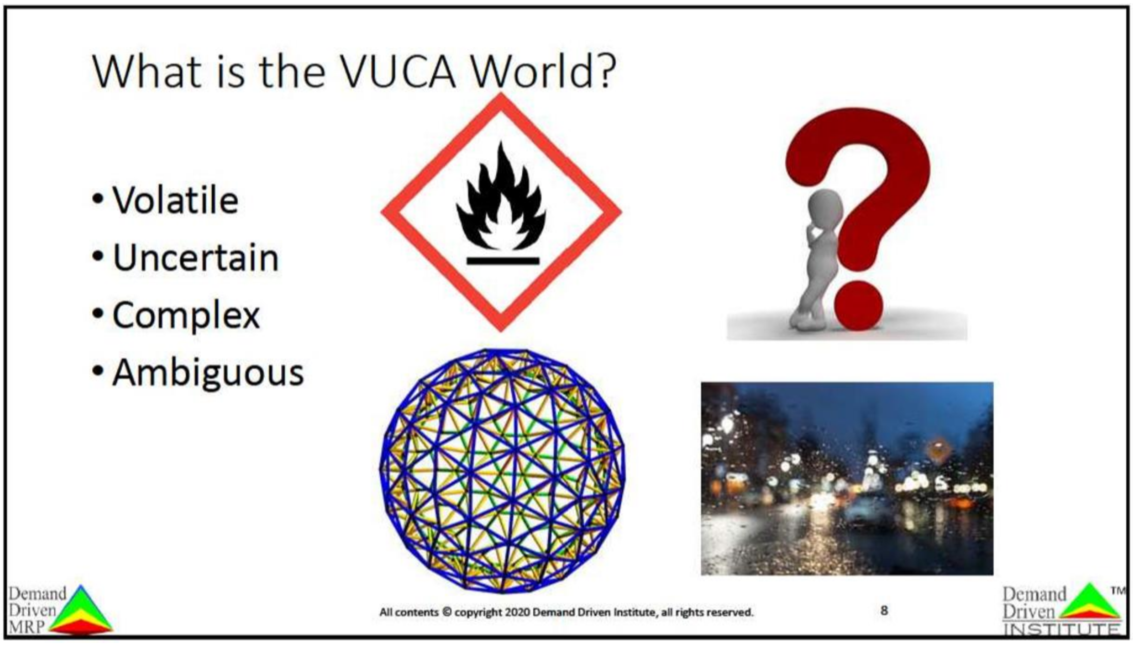


Figure 73. VUCA World explanation /13/.

Considering the Plant structures, how manufacturing plant produces products; is the plant V, A, T or combination type of plant. As known DDMRP characteristics, the Demand Driven MRP method will work on every plant type, even on combination plant types. This is because how DDMRP method is calculating the supply order generation, it's monitored and readjusted all the time across the decoupled point buffers in BOMs (Decoupled explosions).

L.Drucot & E.Ahmed has done an survey to companies: *"What are the Reported benefits and challenges of a DDMRP implementation"*/14/. Fourteen companies responded to survey. One analysis from survey is about inventory standpoint where they have gathered inventory reduction by different industries (Figure 74).

Industry	Repartition
FMCG/Life Sciences/Food & Dairy/Chemicals (Semi-Process)	56%
Mechanical and Assembly	19%
Mills and flow production	7%
Other	19%

Industry	Reduction in Inventory Level
FMCG/Life Sciences/Food & Dairy/Chemicals (Semi-Process)	15%
Mechanical and Assembly	33%
Mills and flow production	29%
Other	16%

Figure 74. Repartition per industry and Average service level improvement by Industry /14/.

As this indicates the different industries using DDMRP, the plant types by industries are different as known. This indicates that DDMRP can be used in different plant types, different industries.

To describe which plant type Wärtsilä Smart Technology Hub would be, the planned plant characteristics must be known. Wärtsilä STH is planned to be able manufacture various marine & energy products. Producing this variety of engines is achieved with two factors; Product modularity and Ecosystem. These two factors play a high role in what plant type STH would be, considering the Ecosystem aspects; Wärtsilä will act like control tower or direction indicator for various partners in huge network. As having an Ecosystem, the work and roles of producing a product can be divided to specialized partners which can produce components or services better than the original supplier, both partner and original supplier benefits from the Ecosystem. Considering the product modularity, it includes the modularity of assembly lines where in top there is divergent assembly points. These two factors combined indicates that the plant structure would be combination where T-plant structure would be in the base, middle and top with A-type middle. At the start of STH, there would be a little bit of V-type plant characteristics at the mid-level structure. Most percentage of V-type structure comes from today’s megatrend in manufacturing, Additive manufacturing. But after products are modularized enough and when the ecosystem is highly operating the V-type characteristics could decrease, this depends if Wärtsilä is keeping additive manufacturing function or transferring function to supplier in ecosystem, see figure 75.

Smart Technology Hub	
Plant type	Percentage
T-type	80%
A-type	10-20%
V-type	0-10%

Figure 75. STH plant type percentages.

STH plant structure is graphically visualized in figure 76.

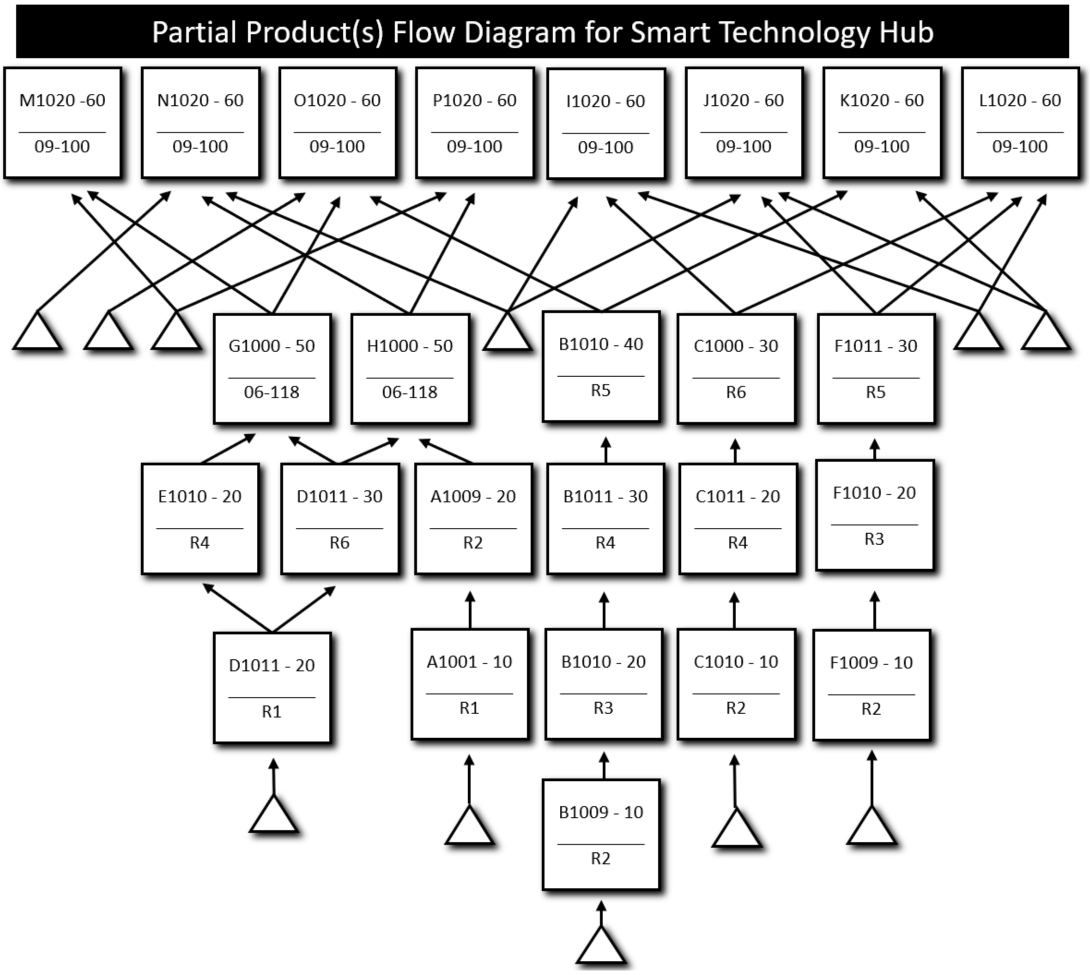


Figure 76. Partial Product(s) Flow Diagram for STH.

4.2 Research Question 2

What is the process of identifying a component which is suitable to DDMRP?

The process of identifying a suitable component for DDMRP starts with reviewing performance reports related to Product, component or item. Reviewing these reports component can be identified to be recommended to be run with DDMRP, but still the Demand Driven method need own kind of data to be run. As well component needs described reports to be identified, there is still an amount of data that needs to be produced for the component to be suitable for DDMRP run or simulation. The whole process to identify if the item or component is suitable and what data is needed to run DDMRP is also based in DDMRP phases 1 & 2. Without the needed data from phase 1 decoupling points cannot be placed in identified product(s) BOM(s). Without needed data phase 2, the Buffer zone & level calculations can't be done. Phases 1 & 2 must be completed in order to be able to simulate and run DDMRP successfully.

Three points to be pointed out about data considerations:

1. Defining product or item to be beneficial to DDMRP run
2. Placing decoupling points in product(s) or item(s) BOM(s)
3. Calculate decoupling point buffer zones & levels

These points are described next stage.

4.2.1 Data considerations

1. Defining product or item to be beneficial to DDMRP run

Company should have data of demand and supply variabilities, inventory-, assets-, material flow-, lead time performances to be able to define suitable components and items to DDMRP.

Applying Possl's first law is good example what to analyse first. The law measures six factors; services, revenues, quality, inventories, expenses and cash flow. When factor performances are known, factors can be then converted to "factors levels": High (3), Medium (2) & Low (1), using levels with radar chart indicate visually the current performance (Figure 77).

The chart is read by these levels, for services, revenues, quality and cash flow high levels means high performance and low level means low performance, to expenses and inventory high level means high expenses and high quantity of inventory and low level means low expenses and quantity.

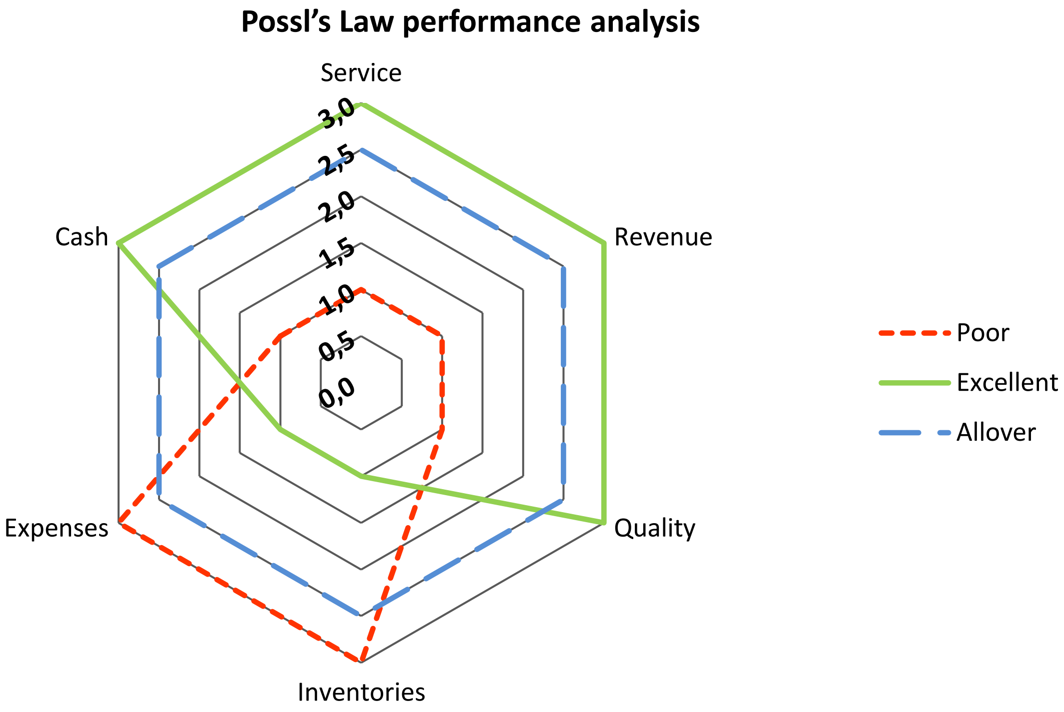


Figure 77. Possl's law performance analysis.

All factors have direct impact on return on investment performance. The most eligible situation is where cash flow, service, revenue & quality is performing high and inventories and expenses are low, as presented then the ROI performance is high. This is a good way to create a visible indication how the company is managing these factors in the moment, and where they should aim in the future. Possl's law performance analysis should be first performed to product family and then to individual products, by doing this a wider point of view can be indicated and the problem areas by product can be treated. Considering data units, these can be expressed as currency, percent or numerals, but it needs to indicate the performance of the factor. From used units, investigator should understand the current performance of the factors.

Considering Demand & supply data, external variabilities should be known and measured. Variability data together with Possl's law factors points the impact to the flow. For in-depth analysis the impact of external variables should be viewed together with internal variabilities to get visibility of the impact to product production. The variability must be defined by either mathematical methods (figure 78) or by defining it just by level. Defining variability is done from historical data and the variability needs to be calculated in certain time window and repeated as time passes. By doing this the variability can be defined as accurate as possible. Defining the time window for variability, there needs to be historical data how variability has been acted in the history, does it have seasonalities, level of variability spikes and outbreaks & inbreaks. The variability needs to be defined that way that it is necessary for the moment and future, the history data should not be huge impact to present time variability. Variability always changes or varies so the calculation needs to be repeated to get the newest, on-going variability in own cycle. This Calculation cycle needs to be defined according to variability levels, as the calculating variability levels is repeated the cycle also. As variability is used to indicate suitable component for DDMRP, it is used also to determine buffer zones and levels. The data format what used can be numeral or percentual, but it needs to show in determined level the variability, High, Medium or low.

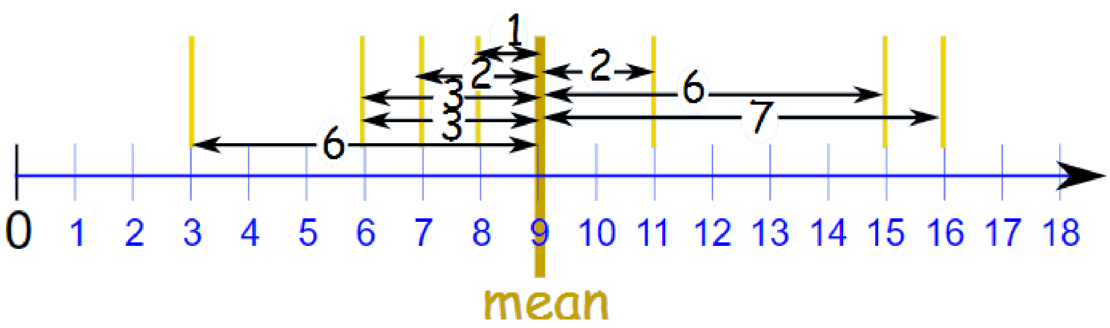


Figure 78. Mathematical formula, Mean Absolute Deviation (MAD) illustrated.

Considering advanced component demand and supply variability, the products and purchased items can be classified to four different variability class by level of variability timing and quantity:

- Smooth: regular demand or supply over time with a limited variation in quantity
- Intermittent: extremely sporadic demand, with no accentuated variability in the quantity of the single demand
- Erratic: regular distribution over time, but large variation in quantity
- Lumpy: extremely sporadic demand or supply, great number of zero-demand or supply periods and large variation in quantity

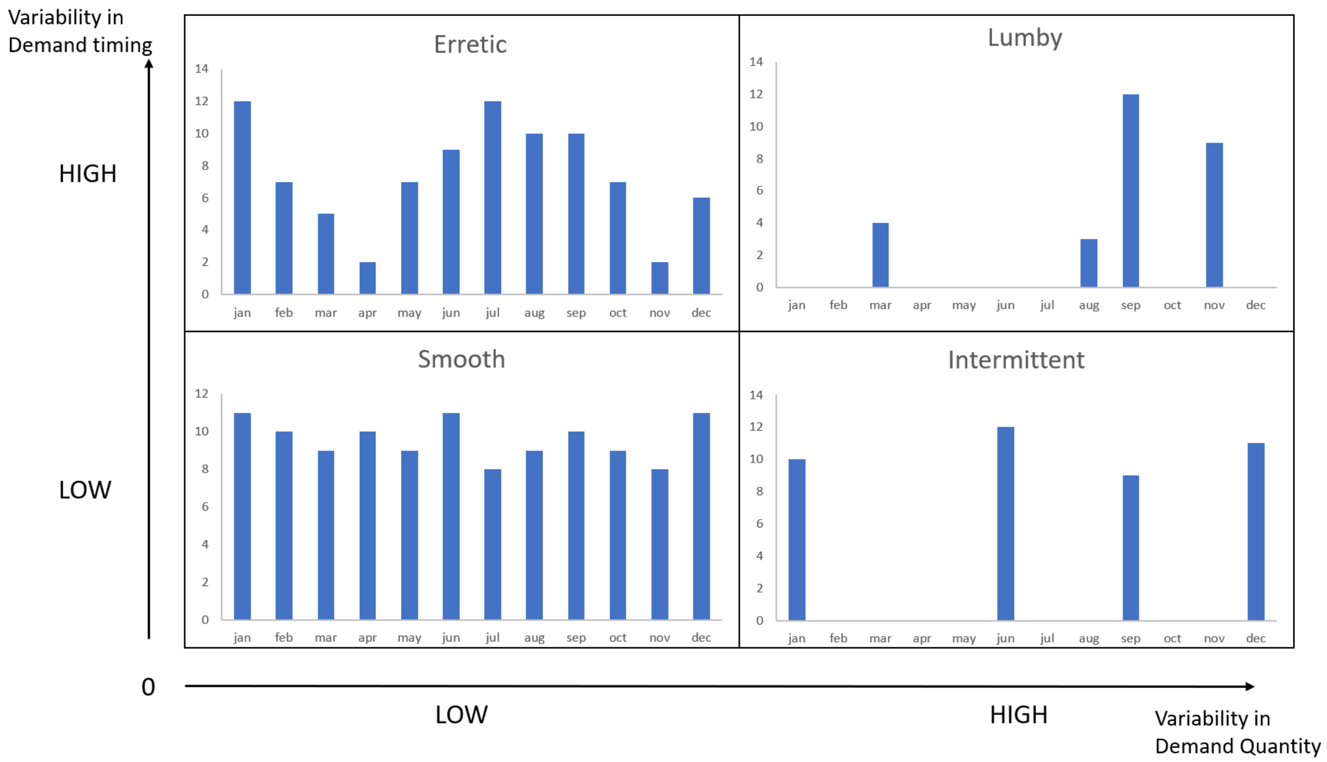


Figure 79. Demand variability patterns illustrated.

Gathering products and purchased items to variability classes increases the visibility which the product suffer both supply & demand signals. A product having many purchased components from many different suppliers can have many different variabilities, thus it is very important to have data to understand where decoupling points should be placed, see figure 79.

SmartChain LLP has released a paper: Setting up buffers for discontinuous demand. SmartChain presents a problem according to variability factor when the demand pattern is “lumby” (Figure 79) or in other words discontinuous demand. SmartChain claim to have discovered that the buffer is not acting like buffer anymore when the demand pattern is acting like lumby:

“We discovered that with such demand patterns, even while using a standard high variability buffer profile, the buffer is not acting like a buffer anymore. What happens is that most customer orders are considered as spike as soon as they enter the spike horizon and this results in the net flow dropping sharply into the yellow or even red zone of the buffer. This will immediately trigger a resupply order that must be supplied to the buffer on time, since the customer order is likely to collapse the buffer. To avoid this from happening the red zone and spike threshold should be sized appropriately. Unfortunately, buffer calculations and parameter settings used in standard buffer profiles do not help. Defining a variability factor and spike threshold combination that work well is difficult and need to be discovered by trial & error for every product” /15/.

They propose a direct solution for this problem with finding factor or variable according to discontinuous demand pattern. They propose new factor which is used when calculating the buffer zones, which is defined as the square root of the total number of days in the period divided by the days with sales. SQ-factor is a multiplier applied in the formula calculating the green & red zone and the spike threshold. As doing this, SmartChain claim result of better working buffer to variability, less variable propagated demand signal and buffer is less likely to collapse due to the single order.

This analysis is good to understand if the company is having many discontinuous demand patterns, the discontinuous demand pattern is not a problem.

2. Placing decoupling points in product(s) or item(s) BOM(s).

To successfully place the decoupling point the data described in point 1 must be reviewed together with Product's Bill of Material and Routing structure or Bill of Operations. Placing decoupling points is all about seeking the areas where we can improve the flow, decrease assets and increase response performance. Data according to BOM needs to be in a form where the products structure shows all child and parents items, Raw materials needed and purchased components according to the product. Product routing structure or BOO is used to indicate the critical operations across the product manufacturing. Routing structure or BOO data must be in condition where the work center related data, item or component, lead times, capacity, costs & scheduling must be available. Data from routing structure or BOO should in from where it indicates order of work centers in manufacturing a product, from raw material or items to final product.

For advanced inventory positioning data indicating the shared components or parts for different products need to be available. Matrix BOM is one of the methods indicating visually the share item and components.

Customer demand variables plays a high role on placing decoupling points, so the key factors responding to customer demand must be known. Data of customer tolerance time, Sales order visibility horizon and market potential lead time must be defined in the unit of number of days.

As pointed out above with these data reviewed together with point 1 data the decoupling points six factors (Figure 80) can be filled and placed precisely to promote and protect the flow of relevant material and information.

Strategic Inventory Positioning Factors	
Customer Tolerance Time	The amount of time potential customers are willing to wait for the delivery of a good or a service.
Market Potential Lead Time	The lead time that will allow an increase of price or the capture of additional business either through existing or new customer channels.
Demand Variability	The potential for swings and spikes in demand that could overwhelm resources (capacity, stock, cash, etc.).
Supply Variability	The potential for and severity of disruptions in sources of supply and/or specific suppliers. This can also be referred to as supply continuity variability.
Inventory Leverage & Flexibility	The places in the integrated BOM structure (the Matrix BOM) or the distribution network that leave a company with the most available options as well as the best lead time compression to meet the business needs.
Critical Operation Protection	The minimization of disruption passed to control points, pace-setters or drums.

Figure 80. Strategic Inventory Positioning Factors.

3. Calculate decoupling point buffer zones & levels

Three variables must be defined: Average Daily Usage, Minimum Order Quantity and Imposed or Desired Minimum Order Cycle. ADU & MOQ is determined in the unit of quantity and the order cycle in number of days.

Considering ADU calculations, the product or item which is produced at the time ADU should be able to be calculated from forecast, history and qualified demand spikes over desired time window. ADU is then used to calculate buffer zones for the decoupling point. Minimum Order Quantity and Desired or imposed order cycle is only used to calculate Green zone, but still those are is needed to be defined because the value of Green zone should be the highest outcome from those formulas and never be lower that MOQ.

Considering ADU length of period and calculation frequency, demand variability needs to be analysed precisely to indicate the need for the length and frequency. If the demand variability is high the length of period should be considered as short because it gives more exact result of current situation. If the demand variability is low the length of period should be considered long, because it gives more exact result of the current situation. About the calculating frequency, if demand variability is high the frequency should be short and if demand variability is low the frequency should be short. As this said the demand variability should be re-analysed in some sort of cycle depending on the demand history and market circumstances according to product. As the demand variability changes then the length of period and frequency of ADU changes also. Wärtsilä can use historical demand data from products which are on the market now, from discontinued or soon to be discontinued product or blend type of data to understand the demand variability and market circumstances in Engine products, how the variability and market circumstances have played along the product lifecycle. Figure 81 illustrates the versions of ADU calculations.

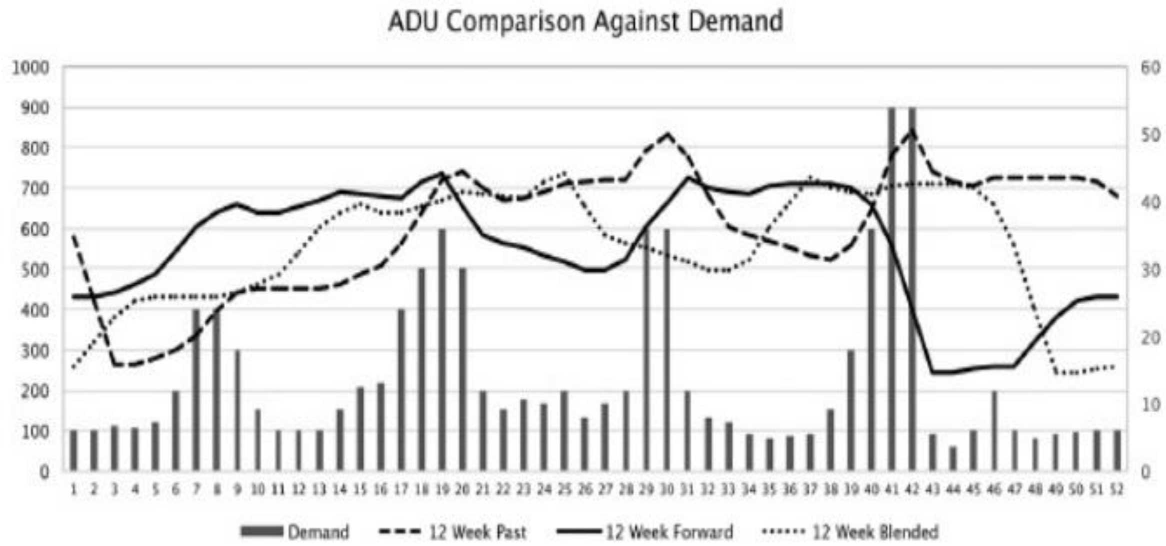


Figure 81. History, forecast and blended versions of ADU illustrated /1/.

For product introduction projected ADU is used with increasing Demand Adjustment Factor (DAF) to create Ramp up adjustment. Projected ADU can be expected amount of product sales from sales & marketing plan or assimilated data from similar or discontinued product.

This said ADU can be defined from qualified spikes, forecast, historical or mix type of data, the decoupling point buffer adapts as actual demand is experienced. The

ADU need to be 40 - 50 percent accurate to decoupling point buffer work fine (Figure 82).

Considering MOQ it can be also qualified from the forecast, history or mix type of data this is because the buffer will adapt as the actual MOQ is experienced.

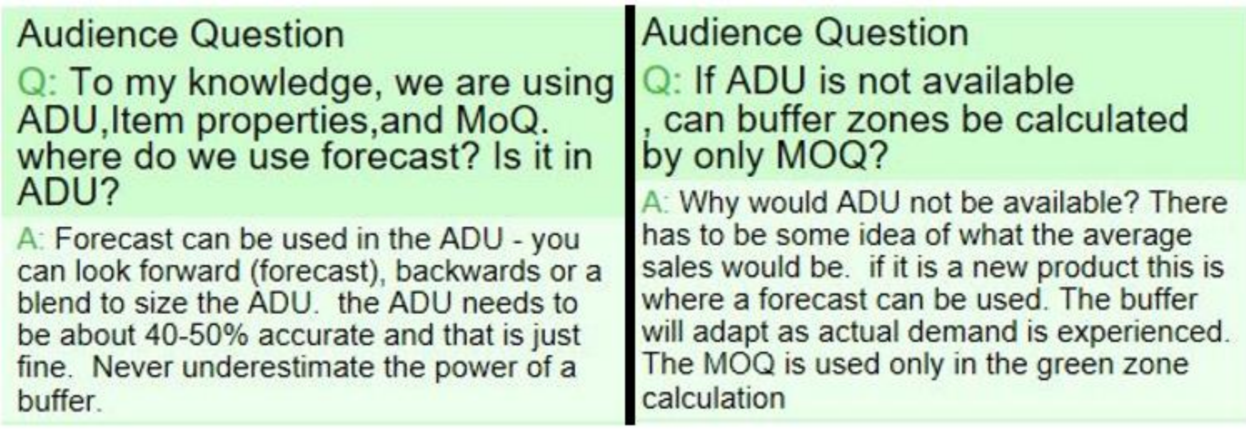


Figure 82. Questions & Answers from Demand Driven Institute, The Four Innovations of Demand Driven MRP Webinar 09.04.2020 /13/.

Considering Desired or imposed order cycle, as this being expected this can be desired average number of days between orders. Defining order cycle can be done from history, future or blend. This can be also time frame from Periodic Order Quantity. As with ADU or MOQ, the true order cycle will accrue over time and the buffer will adapt with it.

The whole process of identifying suitable component is presented as process map in figure 83.

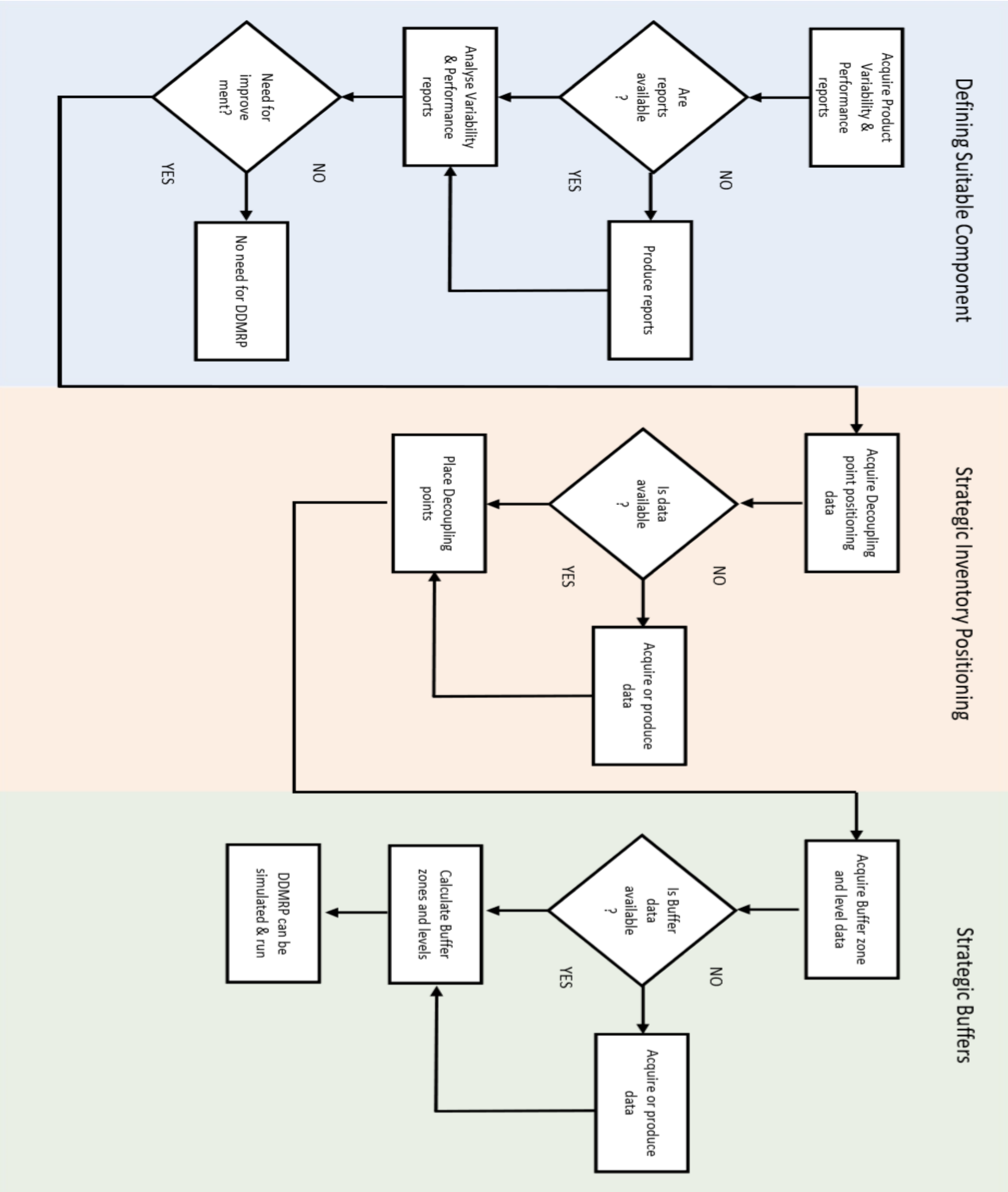


Figure 83. Process map for identifying suitable component for DDMRP.

5 CONCLUSIONS & DISCUSSIONS

5.1 Conclusions of Findings

For describing a suitable component for DDMRP, the component should have data of three points;

1. Defining product or item to be beneficial to DDMRP run
2. Placing decoupling points in product(s) or item(s) BOM(s)
3. Calculate decoupling point buffer zones & levels

In point one the analysed component is defined is it beneficial to run DDMRP. If improvement is necessary or needed it simply means it is beneficial to run DDMRP, if there is no need for improvement component can be run by conventional MRP.

In point two the DDMRP phase 1 is done, Strategic inventory positioning where decoupling points are placed. If these points can be placed the component is not yet suitable for DDMRP simulation or run. This means you need to generate certain type of data to place decoupling points. After the needed data is acquired DDMRP can be run, the component is suitable this far.

Point 3 is last needed point for defining if component is suitable for DDMRP simulation or run. Point 3 needs certain data and if this cannot be indicated it means component is not yet suitable for DDMRP. Producing this data will make the component fully suitable for DDMRP run.

For simplifying the answer: If the component doesn’t have data of these three points it indicates the component is not yet suitable to DDMRP simulation or run. If component have these three points of data, it is suitable for DDMRP.

Considering the process of identifying, the process is done in order, this is because otherwise DDMRP can not work properly. The product needs to be identified as beneficial to be run by DDMRP before the point 2 is carried out. The point 2 where decoupling points are positioned is the most critical part because the positioning decoupling point is strategical move to have responsive inventory, placing decoupling points I describe as a placing points where you have always everything what you need, in a necessary quantity. If you place these decoupling points arbitrarily way the calculated buffers don't serve the flow best way as possible. As the point 2 is completed the best reasonable way as possible, the point 3 will make sure the decoupling point will have the necessary quantity according to demand as it is calculated and DDMRP phases 3, 4 & 5 are completed.

When having all data of these three points of defining suitable component the DDMRP can be run and simulated, there is no need for defining new variables from other sources.

Needed data can be pointed out by these three points:

1. Defining product or item to be beneficial to DDMRP run
   - Product performance reports
   - Demand & Supply variability reports
2. Placing decoupling points in product(s) or item(s) BOM(s)
   - Bill of Material
   - Product routing structure or Bill of Operation
   - Customer tolerance time
   - Sales order visibility horizon
   - Market potential lead time
   - Demand & Supply variability reports
3. Calculate decoupling point buffer zones & levels
   - Average Daily Usage (ADU)
   - Minimum Order Quantity (MOQ)
   - Imposed or Desired Minimum Order Cycle

5.2 Practical implications

The reader of this thesis will understand the principles of conventional MRP, DDMRP and Manufacturing plant structures. The reader understands today's Supply Chain circumstances & characteristics and the conventional MRP performance problems and how DDMRP is presented to manage the new normal.

The thesis gives a direction of what information and data to get when considering using DDMRP as a planning method to Product, component or item. The thesis describes the process of identifying suitable component with data considerations, reader can follow this thesis to be able define the needed data in the right order. The thesis can be used to indicate what data is needed and what data needs to be produced and generated. The thesis gives principles how to produce the needed data. The thesis will give a view from thesis worker what manufacturing plant structure Wärtsilä Smart Technology Hub would be and why.

5.3 Practical applications

The thesis is limited to literature view, meetings with senior development manager and to webinars. Any empirical study methods has not been used to study and prove the thesis subject and answers to be right or correct. Meetings with Senior development manager would been beneficial to extend couple times to STH DDMRP team to get more discussion and conclusions. Whole literature according to thesis was new for me and I did do my best to understand the principles of literature in the thesis time frame.

5.4 Future recommendations

Future recommendations for DDMRP, I recommend Wärtsilä to track Product, Component & item principles what have presented in this thesis to be needed for suitable for DDMRP run. With this tracking Wärtsilä can understand the needed work of data producing and generations when implementing DDMRP.

As the DDMRP characteristics and principles has been presented I strongly recommend to study and consider DDMRP implementation. This is because DDMRP offers more accurate Resource planning method to the new normal than conventional. As the supply chain is complex and adaptive systems the conventional MRP cannot react the way wanted if the planning method is linear system. If the characteristics and circumstances of supply chain are complex and adaptive why not use method which can respond in the same manner? The best way to respond this is understanding of DDMRP and Artificial Intelligence. Many Company CEO's like Elon Musk have told and even warned about Artificial Intelligence. Artificial Intelligence allows machine learning to high levels, the development will be exponential after the true development of self-learning AI. Artificial intelligence and machine learning is the best way to respond to complex and adaptive systems because they are also complex and adaptive systems. Thus I recommend Wärtsilä to invest understanding towards Artificial Intelligence and DDMRP, by these two the best planning method can be acquired in the future. The thinking of Artificial Intelligence is not all about today's world, it is about thinking about future generations in our world. The company which have implemented first use of Artificial Intelligence and Machine Learning will be the best of the competitors.

REFERENCES

/1/ Ptak & Smith (2016) Demand Driven Material Requirement Planning (DDMRP). Industrial press, South Norwalk, ISBN ePDF 978-0-8311-9384-3

/2/ Demand Driven Institute (2014) Building a Demand Driven Supply Chain. Moving industry from the world of push and promote to the world of position and pull. Accessed 09.01.2020. https://slideplayer.com/slide/12266426/

/3/ LeeJ. Krajewski, Manoj K. Malhotra & Larry P.Ritzman Operations Management Processes and Supply Chains Twelfth Edition ISBN-13 978-1-292-25993-2

/4/ MRP. Accessed 23.01.2020. https://www.inc.com/encyclopedia/material-requirements-planning-mrp.html

/5/ APICS Dictionary The essential Supply chain reference Fourteenth edition ISBN 978-0-9882146-1-3.

/6/ Operation management Chapter 14 – MRP and ERP 2008 Prentice hall, INC. Accessed 28.01.2020. https://www.slideserve.com/urielle-gould/operations-management

/7/ MRP glossary of Production scheduler Asprova. Accessed 05.02.2020

https://www.asprova.jp/mrp/glossary/en/

/8/ Demand Driven Institute Dictionary Accessed 05.02.2020. https://139b7ba6-57f5-40f4-a9cb-3c134e42ba5c.filesusr.com/ugd/390972_5ae145c6c37446a4af4920a50ba2380b.pdf

/9/ Success or struggle: ROA as a true measure of business performance, Report 3 of the 2013 Shift Index series From the Deloitte Center for the Edge. Accessed 10.02.2020. https://www2.deloitte.com/content/dam/insights/us/articles/success-or-struggle-roa-as-a-true-measure-of-business-performance/DUP505_ROA_vFINAL2.pdf

/10/ Manufacturing requirements planning: The four critical questions answered from Chapter 3, Orlicky's MRP, Third Edition. Accessed 10.02.2020. https://searcherp.techtarget.com/feature/Manufacturing-requirements-planning-The-four-critical-questions-answered

/11/ The Power of Decoupling, Unlocking the Secret to Demand Driven Material Requirements Planning (DDMRP) A white paper by the Demand Driven Institute 2015. Accessed 15.03.2020. https://www.demanddriveninstitute.com/articles

/12/ M.M. Umble & M.L. Srikanth (1997) Synchronous Management Profit-based manufacturing for the 21st century Volume 2. ISBN 0-943953-07-3.

/13/ Demand Driven Institute, The Four Innovations of Demand Driven MRP Webinar. Held in 09.04.2020.

/14/ Investigation of Potential Added Value of DDMRP in Planning Under uncertainty at finite Capacity by L.Drucot & E.Ahmed. Accesed 23.4.2020 https://139b7ba6-57f5-40f4-a9cb-3c134e42ba5c.filesusr.com/ugd/390972_dec6ac7b537549c0a5a2e9e5c0340775.pdf

/15/ Setting up DDMRP buffers for discontinuous demand by SmartChain International LLP. Accessed 24.4.2020. https://139b7ba6-57f5-40f4-a9cb-3c134e42ba5c.filesusr.com/ugd/af37d3_fc0e513c6066471eaf804da781ca8ba6.pdf

/16/ This is Wärtsilä. Accessed in 26.4.2020 https://www.wartsila.com/about