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SUPPLY CHAIN INTEGRATION WITH DEMAND DRIVEN MATERIAL REQUIREMENTS PLANNING SYSTEM
Case: Wärtsilä 4-Stroke

Master's Thesis in
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ABBREVIATIONS

ADU	Average daily usage
ASRLT	Actively Synchronized Replenishment Lead Time
ATO	Assemble to order
AWU	Average weekly demand
BOM	Bill-of-material
CLT	Cumulative lead time
CODP	Customer order decoupling point
CONWIP	Constant work in process
CPFR	Collaborative planning, forecasting and replenishment
CR	Continuous replenishment
CRP	Capacity requirements planning
CV	Coefficient of variation
D	Distributed item
DDMRP	Demand driven material requirements planning
DP	Decoupling point
ECR	Efficient consumer response
ERP	Enterprise resource planning
ETO	Engineer to order
FG	Finished goods stock levels
Inv.	Inventories
KPI	Key performance indicator
LLC	Low-level code
LTM	Lead time managed

M	Manufactured item
MLT	Manufacturing lead time
MO	Manufacturing order
MOQ	Minimum order quantity
MPS	Master-production-schedule
MRP	Material requirements planning
MRP II	Manufacturing resource planning
MTO	Make to order
MTS	Make to stock
OBA	Open book accounting
OD	Operational development
OPP	Order penetration point
OTD	On time delivery
OTOG	Over top of green buffer position
P	Purchased item
PAF	Planned adjustment factor
P/D ratio	Production to delivery lead time ratio
PO	Purchase orders
PLT	Purchasing lead time
RACE	Return on average capital employed
RCCP	Rough-cut capacity plan
RDV	Relative demand volatility
RO	Replenished over-ride
ROI	Return on investment
ROIC	Return on invested capital

SCC	Supply chain collaboration
SKU	Stock keeping unit
SOWD	Stock out with demand
TO	Transfer orders
TOG	Top of green buffer zone
TOR	Top of red buffer zone
TOY	Top of yellow buffer zone
TR	Total revenue
VMI	Vendor-managed-inventory
WIP	Work in process

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VAASAN YLIOPISTO
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TIIVISTELMÄ

Tässä tutkimuksessa selvitetään, kuinka kohdeyritys Wärtsilä 4-Stroke voisi ottaa käyttöön uudenlaisen materiaaliohjausmenetelmän *Demand driven material requirements planning* eli DDMRP:n. DDMRP menetelmän teoria ja ensimmäiset käytännön sovellukset ovat keskittyneet vain yhden yrityksen sisäisen toimitusketjun integroimiseen. Verrokkiyrityksenä toimii LeTourneau Inc. joka on onnistunut DDMRP:n avulla kasvattamaan neljässä vuodessa pääomantuottoaan neljästä prosentista 22 prosenttiin. Tässä tutkimuksessa selvitetään, kuinka menetelmää voisi hyödyntää myös alihankkijaverkoston ohjaamiseen, koska Wärtsilä 4-Stroken tuotteiden valmistus tapahtuu suurelta osalta alihankkijayrityksissä.

Aiemmat tutkimustulokset ovat osoittaneet, että toimitusketjun integroimisella on mahdollista pienentää varastoihin sitoutunutta pääomaa, samalla kuin toimitusketjun reagointikyky nopeutuu. Tässä tutkimuksessa selvitetään voisiko kohdeyritys saavuttaa vastaavanlaisia tuloksia, integroimalla alihankkijayritykset mukaan toimitusketjuunsa, jota ohjattaisiin DDMRP menetelmällä. Tutkielma toteutetaan arvioimalla menetelmän soveltuvuutta ja käyttöönottoa käyttämällä kolmen esimerkkimateriaalin toimitusketjuja.

Tutkimustulosten ensimmäisessä osassa kuvataan DDMRP ohjausta kolmelle esimerkkimateriaalille. Toisessa osassa esitetään, kuinka käyttöönotto voitaisiin toteuttaa yhteistyössä alihankkijaverkoston kanssa. Tutkimuksen ensimmäisen osan laskennalliset tulokset osoittavat, että yhden esimerkkimateriaalin toimitusketjun varastoihin sitoutunutta pääomaa voitaisiin pienentää jopa 47% nykyisestä tasosta. Se vastaisi 809 tuhannen euron rahallisia säästöjä. Samanaikaisesti toimitusketjunhallinta helpottuisi ja nopeutuisi, kuin materiaalien toimitusajat lyhenisivät. Kahden muun esimerkkimateriaalin kokonaisvarastojen muutos tulisi selvittää yhteistyössä alihankkijayritysten kanssa toteutetussa DDMRP:n käyttöönottoprojektissa. Tutkimuksen toisen osan tuloksissa esitetään projektiehdotus, jonka avulla kohdeyritys voisi yhteistyössä alihankkijoiden kanssa toteutettaa DDMRP:n käyttöönottoprojektin. Projektissa luotaisiin integroitutoimitusketju, jonka tavoitteena olisi parantaa kannattavuutta, pienentää kokonaisvarastoja ja nopeuttaa toimitusketjun reagointikykyä.

AVAINSANAT: Logistiikka, toimitusketjut, tuotannonohjaus, tuotannonsuunnittelu

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ABSTRACT

This study investigates how the case company Wärtsilä 4-Stroke could implement in its supply chain new material management system called as *demand driven material requirements planning* (DDMRP). The previous DDMRP literature is focused on single company implementations where benchmark company LeTourneau Inc. have been capable to increase its return on invested capital from 4% to 22% in four years by taking the DDMRP in use. This study aims to investigate how the DDMRP system could be extended for controlling also the supplier network since the production of Wärtsilä 4-stroke products is performed into great extent by external suppliers.

Previous supply chain studies show that supply chain synchronization leads to lower inventory levels and improved responsiveness. This study strives to investigate if the case company could achieve similar results by integrating its supply chain with the DDMRP. The investigation is performed by using supply chains of three example case components supplied to the Vaasa factory located in Finland.

First part of the research results is dedicated on illustrating the DDMRP system for three example cases. Second part shows how the implementation could be done in collaboration with suppliers. In the first part is shown calculated results how, with the DDMRP integrated supply chain, the total inventory holding of first example could be reduced by 47%, which would mean 809 000 euros reduction in working capital. At the same time the responsiveness could be improved by having shorter component delivery lead time. For two remaining example cases the total inventory reduction potential should be investigated with the suppliers in collaborative DDMRP implementation project. The second part of results presents a project proposal how such collaborative DDMRP implementation project could be performed. Objective of the project would be to create integrated supply chain which purpose would be to improve profitability, reduce total inventories and improve supply chain responsiveness.

KEYWORDS: Supply chain management, supply chain collaboration, customer order decoupling point, material requirements planning, supply chain integration.

1. INTRODUCTION

Statement of *"it is widely accepted that creating a seamless, synchronized supply chain leads to increased responsiveness and lower inventory costs"* (Holweg, et al., 2005) gives the motivation for this study to find out how the case company, and related extended supply chain, could achieve this with a *"demand driven material requirement planning"* (DDMRP) system. DDMRP system is introduced to greater audience by Carol Ptak and Chad Smith in their 2011 published book: *"Orlicky's material requirements planning, 3rd edition"* where the DDMRP is marketed to help companies to shorten their lead times, improve on time delivery performance and enable more sales with the same capacity and with less total inventory than what conventional material requirements planning (MRP) would enable. The early adopters of DDMRP system have gained significant improvement in the company return on invested capital (ROIC) together with improved customer satisfaction and revenue growth. This value proposition of DDMRP offers interesting alternative for conventional MRP on helping companies to achieve their primary goal of creating value for their owners by generating improved return on investment (ROI) which is boosted with positive revenue growth. To provide an overview how the implementation of DDMRP could help in this value creation the first research question is outlined as follow:

RQ 1: *How the supply chain synchronization with DDMRP implementation could improve responsiveness and lower inventory cost?*

Authors of DDMRP suggest companies to conduct all of the "*five primary components of demand-driven MRP"* (2011, pp. 388) when implementing the system. The original implementation approach from the authors (Ptak & Smith, 2011) is limited to consider DDMRP implementation only in vertically integrated value chain of single company. The existing theory does not provide sufficient theoretical model for the implementation in non-vertically integrated supply chain where the products are produced in dispersed network of companies when the *relationship* management plays major role on controlling the total value chain. This study tries to bridge this research gap by investigating how the DDMRP could be implemented across supply chain partners in non-vertically integrated configure-to-order manufacturing environment. For this research purpose the second research question is defined as:

RQ 2: *How to implement DDMRP in non-vertically integrated supply chain?*

Both of the research questions are studied with an *embedded multiple-case study method* (Yin, 1994) in a single case company called Wärtsilä 4-Stroke. Wärtsilä Corporation is a *"global leader in complete lifecycle power solutions for the marine and energy markets* with *operations in more than 200 locations in nearly 70 countries around the world"* (Wärtsilä , 2014). The organisation is structured into three divisions called Ship Power, Power Plants and Services, from which the Ship Power is the division where the case company Wärtsilä 4-Stroke belongs to. Ship Power supplies "*engines and generating sets, reduction gears, propulsion equipment, control systems and sealing solutions for all types of vessels and offshore applications"* (Wärtsilä , 2014) for all marine segments where the company has a strong and acknowledged market position in producing, supplying and serving of ship machinery and systems. Wärtsilä 4-Stroke is one of the business lines in the Ship Power division and it is focused on producing and supplying the engines and generating sets from fully owned production sites located in Finland, Italy and Brazil together with joint venture production sites in China.

This case study is performed at the Finland production site located in Vaasa with an aim to investigate with three different types of case components how the supply chain of complete 4-stroke engine assembly line could be managed, integrated and synchronized with the collaborative DDMRP implementation. Assumption is that if the system could improve supply chain responsiveness and lower costs for the three case component supply chains, then the system could be considered to be extended for the full spectrum of strategic components supplied to assembly line of Vaasa production site. After the system would be piloted and validated in Finland the system could be extended to the other production sites of 4-Stroke and possibly also for other business lines of Ship Power organisation.

2. THEORY

The term *responsiveness* has received great variety of different definitions from the academia, practitioners and consultants. Reichhart and Holweg (2007) collect comprehensive list of alternative definitions from academia where the common determination for responsiveness is the ability to react into market demand with short delivery and process lead times, with less inventory and with faster capability to introduce new products due to less stock in the supply chain. According to Martin Christopher (2011, p. 36) the *responsiveness* is achieved by becoming demand driven instead of forecast driven. The authors of DDMRP (Ptak & Smith, 2011; Smith & Smith, 2014) claim that the conventional MRP system forces organizations and supply chains to operate in forecast driven manner while the DDMRP would enable companies and supply chains to become demand driven.

The DDMRP includes one important step for becoming demand driven called *strategic inventory positioning*, which mean selection of *"hybrid"* supply chain strategy from the *four generic supply chain strategies* (Christopher, 2011, p. 2011). Important aspect for creation of the responsiveness supply chain is *postponement* (Childerhouse & Towill, 2000; Christopher, et al., 2006; Wade, et al., 2012). The postponement strategy has been the driving enabler example for Dell Inc. in creation of their widely acknowledged and referred market responsiveness supply chain. In Dell's supply chain the postponement strategy is created with four techniques: *modularity of product, demand management, vendor managed inventory* and related *supply chain partnerships* shown in Figure 1 below (Kumar & Craig, 2007).

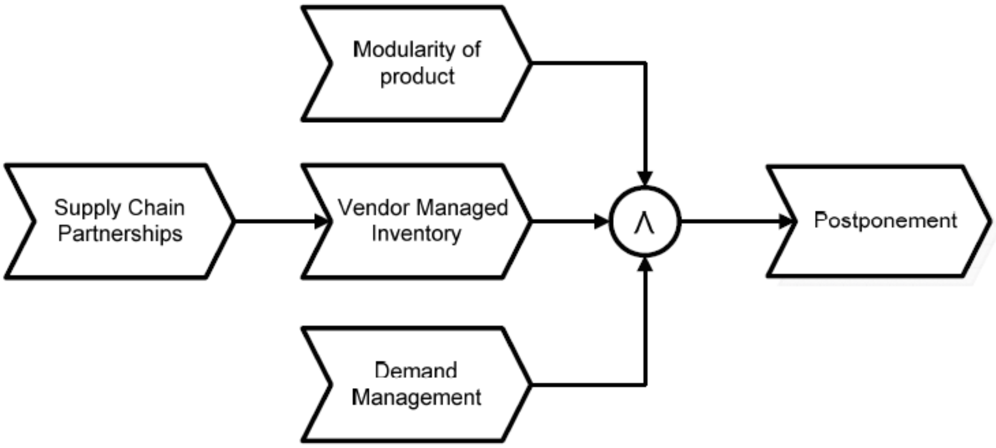


Figure 1: Techniques used by Dell for postponement strategy (Kumar & Craig, 2007)

The rest of the theoretical part of this research paper is divided into three sections which are relevant for investigating how the responsiveness could be created in the case supply chains with the inter-organizational DDMRP implementation. The first section explains the theory of *"conventional material requirements planning"* which is currently the most applied manufacturing planning and control system in the modern manufacturing companies, including also the case company. Second section takes a look on theory of *"demand driven material requirements planning"* (DDMRP) and explain what the main differences from conventional MRP system are. The third section is dedicated on describing the theoretical aspects of *supply chain collaboration* (SCC) which is missing from the initial DDMRP theory but is necessary to take into consideration when designing the inter-organizational DDMRP implementation.

2.1 Conventional MRP

The field of production and inventory management experienced revolutionary change in the 1970's when Joseph Orlicky published the first book where a new material management tool was introduced. Some industrial pioneers had already piloted this new tool before 1960's but Joseph Orlicky was the first who introduced the computerized material requirements planning tool – MRP – for the public audience in the 70's. (Ptak & Smith, 2011, pp. 3-4). In the 80's the MRP was updated into manufacturing resource planning – also known as MRP II – where the *"financial analysis and accounting functions"* were added into the computerized MRP tool. Technological progress in the computing power of computers enabled increased amount of MRP II software providers to enter into market and make the tool commercially available for majority of companies (Ptak & Smith, 2011, pp. 379-380). In the 90's the MRP II evolved into enterprise resource planning – ERP – which connected all of the resources from different functions of one enterprise under the control of one and same centralized system and database. Today it is hard to find a company without ERP system and according study by Aderbeen Group (2006) 79 percentage of companies with ERP systems are using the MRP module as a part of their ERP system (Ptak & Smith, 2011, p. 4). It is reasonable to generalize that the MRP is today well known *"basic tool"* used by majority of companies who are running a manufacturing operations (Vollmann, et al., 2005, p. 188).

At time before MRP the inventory management was based on statistical reorder points where the production of any part was triggered by an inventory level reduction below a predetermined point called as the reorder point. Originators of MRP, including Joseph Orlicky, notice that this approach is not suitable for all of the products by explaining that the trigger for production should be adjusted according to the nature of the demand whether the demand is **independent** or **dependent**. For products which companies are selling the demand is **independent** and for the components of these products the demand is **dependent**. In the MRP system these two types of demand are linked together by using the production schedule of **independent** demand items to calculate backwards when the production of **dependent** demand item should started so that the produced component would be available in the production of **independent** demand item. In the statistical reorder point method this connection between independent and dependent demand items is missing. The scheduling calculation done by MRP is often called as a **push** system where the products are pushed into the system based on the calculated schedule what items should be produced and when. The reorder point system and Toyota's kanban system are often called as **pull** systems since in those products are pulled in to production when inventory is consumed. (Hopp & Spearman, 2011, pp. 114-115).

The scheduling calculation in MRP is based on the **bill-of-material (BOM)** of the produced product. The BOM is a description of the product structure of the complete end product **–** **independent** item **–** where is described what parts and components – **dependent** items **–** are required for producing the end product**.** The **dependent** items are called as the lower level items and the **independent** item is called as the end-item. In some cases also lower level items can have **independent** demand if those are sold example as spare parts for previously sold end-items. For the MRP calculation each item in the BOM has a **low-level code (LLC)** which tells the lowest level in the BOM where the item is used. The end-item has LLC of 0 and when the BOM structure is moved downwards the LLC number increase. (Hopp & Spearman, 2011, p. 116). Below in Figure 2 is illustrated an example BOM with LLC numbers where the LLC number of component 200 is given by the lowest level where it is used and hence the LLC is 3 instead of 1.

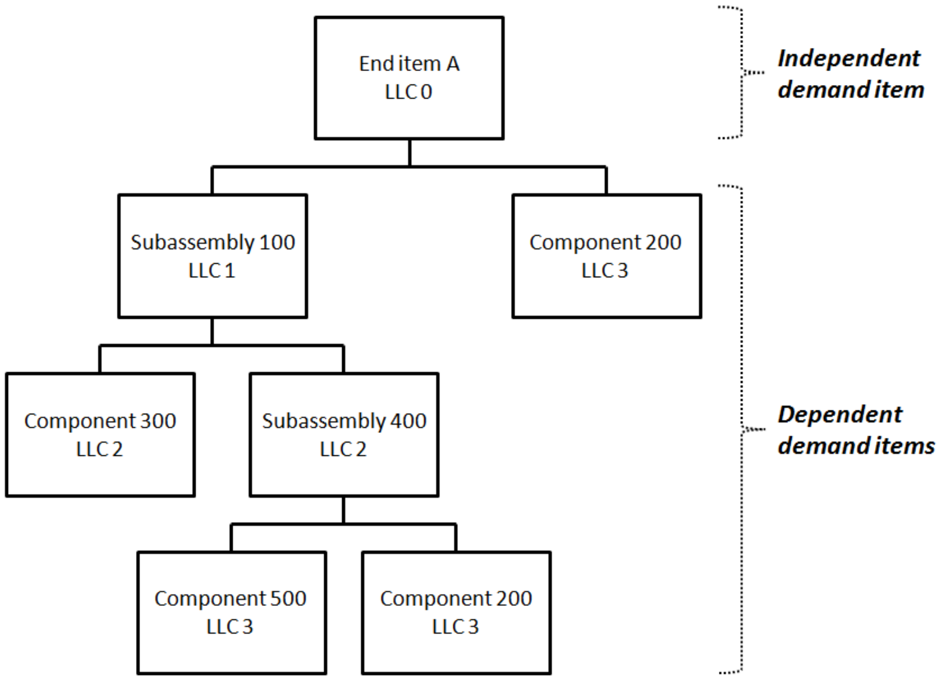


Figure 2: Example BOM.

The actual material requirement calculation is done for the **dependent** items by using the BOM information and scheduled requirements of **independent** items which are planned in **master-production-schedule (MPS)**. In the MPS is defined the **gross requirements** of independent demand items, current **on-hand** inventory levels and **scheduled receipts** of previously released purchase and manufacturing orders. These features are used in MRP to create five basic steps for each part in the BOM by starting from the end level items and by iterating level-by-level to the lowest level items. according to Hopp and Spearman (2011) these five steps are:

1. **Netting:**
   *"Determine **net requirement** by subtracting on-hand inventory and any scheduled receipts from the gross requirements".*
2. **Lot sizing:**
   *"Divide the netted demand into appropriate **lot sizes** to form jobs."*
3. **Time phasing:**
   *"Offset the due dates of the jobs with **lead times** to determine start times."*

4. **BOM explosion:**
   ”Use the start times, the lot sizes, and the BOM to generate gross requirements of any required components at the next level(s)”.
5. **Iterate:**
   ”Repeat these steps until all levels are processed”.
   (Hopp & Spearman, 2011, pp. 116-117).

For the LLC 0 items the gross requirement comes from MPS and for the LLC > 0 the requirement is a result of previous MRP iterations or coming from the independent demand coming example from demand of spare part sales. If the calculated **net requirement** goes below zero there is generated a material requirement. The *jobs* are either purchase or manufacturing orders where the *appropriate lot size* is dependent on the optimal batch size in own production or from the source of supply, the *lead times* are based on the required time to produce the part or to ship the purchased part, the determined *start time* is either the start of assembly of a sub-part or the date when to create the purchase part for the purchase component. From the MRP iteration of the five steps through all of the BOM levels, MRP generates three kinds of outputs:

1) *Planned order releases* – creation of new *jobs*
2) *Change notices* – rescheduling of existing *jobs*
3) *Exception notices* – report of discrepancies between planned and what will realize. (Hopp & Spearman, 2011, pp. 116, 120-121).

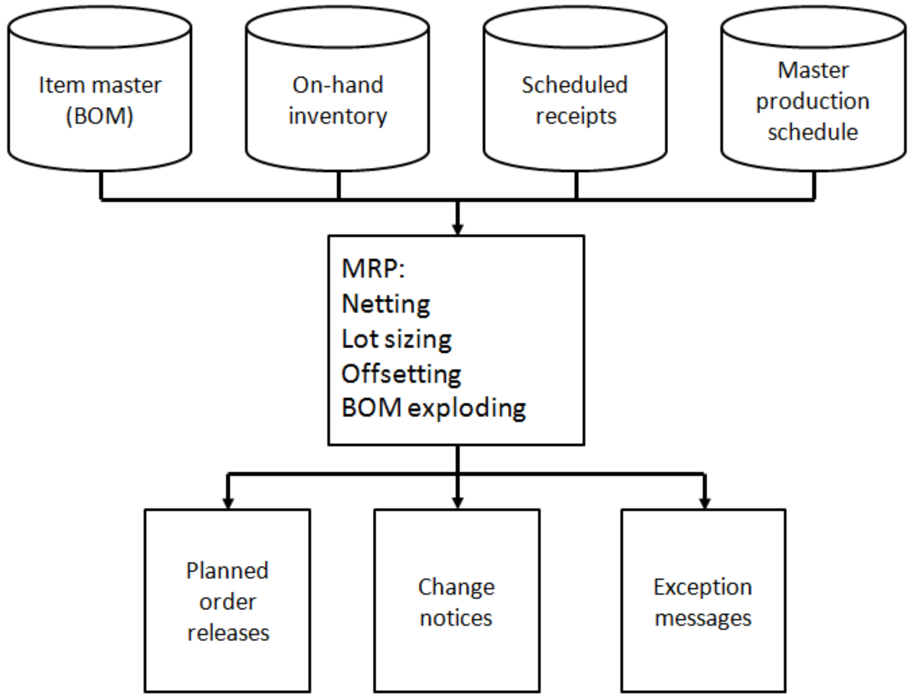


Figure 3: Schematic of MRP. **(Hopp & Spearman, 2011, p. 117)**

The whole MRP calculation process, from the inputs to the outputs, is presented above in Figure 3: *Schematic of MRP***.** For more detailed description on how the MRP calculates the inputs into outputs the reader is suggested to take a closer look on Hopp & Spearman (2011, pp. 119-135) and into Vollman et al (2005, pp. 188-215).

Despite MRP become widely applied tool there was already in the beginning identified several problems with the MRP from which Hopp & Spearman (2011, p. 135) point out three major ones which partially boosted the evolution of MRP II and ERP systems:

1) *"Capacity infeasibility of MRP schedules"* – MRP uses fixed lead time in the planning of operations without consideration of capacity load with an assumption of infinite available capacity which creates problems when the capacity is highly or fully utilized. In the MRP II this problematic is overcome with adding of **rough-cut capacity plan (RCCP)** and **capacity requirements planning (CRP)** modules which are connected into master production schedule (MPS) which makes the system *"capacity-feasible"*.

2) *”Long planned lead times”* – Because MRP uses static lead times in the calculation the planners tend to use lead times which are above the actual average lead time to be sure that the variability of processes can be covered within the planned lead time and hence the late deliveries, and associated negative consequences, can be avoided. Problem with long planned lead time is that it will lead into higher inventory levels and lower system responsiveness. In order to overcome the variability occurring in processes the MRP uses safety stocks and safety time.
3) *“System nervousness”* – Coming from the observation that small changes in system input, *master production schedule* (MPS), can cumulate into large changes in system output, *planned order releases, change notices and exception messages*. Due to this *nervousness* the previously scheduled amount and order can become unfeasible when the system generates change notices for existing orders and reschedules the planned release of new ones. (Hopp & Spearman, 2011, p. 136).

2.2 Demand driven MRP

Demand driven material requirements planning (DDMRP) is an inventory and materials management solution developed and introduced by Chad Smith and Carol Ptak in their 2011 published book: *"Orlicky's Material Requirement Planning- Third Edition"*. DDMRP is an innovative hybrid solution which combines two fundamental inventory management techniques: order-point system and MRP system. Order point system uses past consumption data for forecasting future demand which is used for defining correct re-order points for each parts of the BOM of produced product. MRP system is more future and product oriented where the past consumption history is ignored and part requirements are scheduled by using the BOM structure and master production schedule of produced product (Ptak & Smith, 2011, pp. 49-50). Purpose of DDMRP is to overcome some of the problematic areas of conventional MRP systems by introducing principles borrowed from theories of Distribution Requirements Planning (DRP), LEAN, Six Sigma and Theory of Constraints in combination with the authors own innovations of: "*Actively Synchronized Replenishment Lead Time (ASRLT)", "Matrix Bill-Of-Material (BOM)"* and their new way of buffer level calculation and control. The appendix 1 includes list of key differences between traditional MRP and DDMRP (Ptak & Smith, 2011, p. 490).

The theories behind DDMRP are mainly known, accepted and partially applied in wide variety of industries and academia and hence the ingredients of DDMRP have already been available for companies (Ptak & Smith, 2011, pp. 387-388). Purpose of DDMRP is to create integrated and robust supply chain design and control solution where companies can improve Return-On-Investment (ROI) by having less bullwhip effect in the whole chain through better responsiveness and visibility in the chain. The beauty of DDMRP is its comprehensive approach on connecting different theories into simplified, practical and easy to follow solution. The solution itself contains five primary components which companies needs to follow in DDMRP implementation. The details of these five components are explained in following sub-chapters and the general view on the process of implementation is presented on Figure 4 below. (Ptak & Smith, 2011).

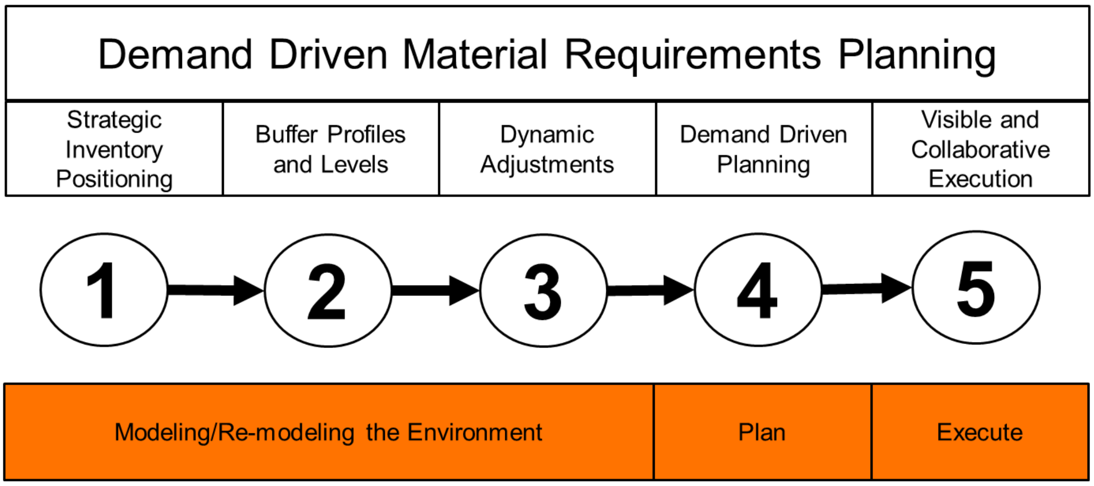


Figure 4: The five components of DDMRP (Ptak & Smith, 2011, p. 390)

2.2.1 Component 1: Strategic inventory positioning

The first step in the DDMRP implementation is referred as *"Strategic inventory positioning"* where the purpose is to define which items in the bill-of-material (BOM) should be buffered in order to create better control and visibility for the supply chain. The process is rather straightforward where the parent items are exploded into child level items to create visualization on the lead times in the BOM. DDMRP uses "*Actively synchronized replenishment lead time*" (ASRLT) unlike the conventional MRP where the lead times are calculated with *"Cumulative lead time"* (CLT), *"Manufacturing lead time"* (MLT) and "*Purchasing lead time"* (PLT) (Ptak & Smith, 2011, p. 65). The CLT, MLT and PLT are defined in APICS Dictionary as below. Figure 5: CLT, MLT and PLT shows with simple example BOM how these are interrelated:

Cumulative lead time (CLT): "*The longest planned length of time to accomplish the activity in question. It is found by reviewing the lead time for each bill of material path below the item; whichever path adds up the greatest number defines cumulative lead time."* (Ptak & Smith, 2011, p. 66).

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 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."* (Ptak & Smith, 2011, p. 65).

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."* (Ptak & Smith, 2011, p. 66).

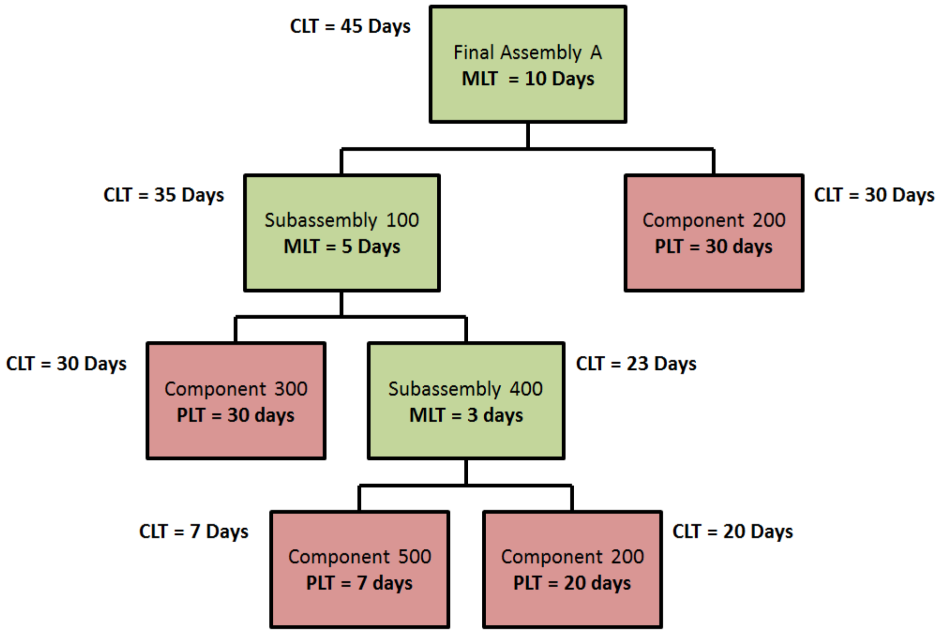


Figure 5: CLT, MLT and PLT

The difference between lead times, CLT, MLT and PLT, of conventional MRP and ASRLT used in DDMRP is that ASRL takes into consideration the strategic stock positions in relation to BOM structure. While CLT describes the full longest path in BOM structure and MLT/PLT describes only lead time of single part, the ASRLT is used to calculate *"longest unprotected or unbuffered sequence in the BOM for a particular parent"* (Ptak & Smith, 2011, p. 394). The purpose of ASRLT is to find out the most realistic lead time for parent level items where the CLT would in most cases indicate overestimated lead time and on the other hand pure MLT would indicate dramatic underestimate, unless all of the lower level parts are stocked (Ptak & Smith, 2011, p. 394). In example below, Figure 6, **components 300 and 200** are stocked items when the ASRLT of **final assembly A** would be 25 days defined by the longest unprotected path in the BOM. If components 300 and 200 would not be buffered then the ASRLT of final assembly A would be equal to CLT.

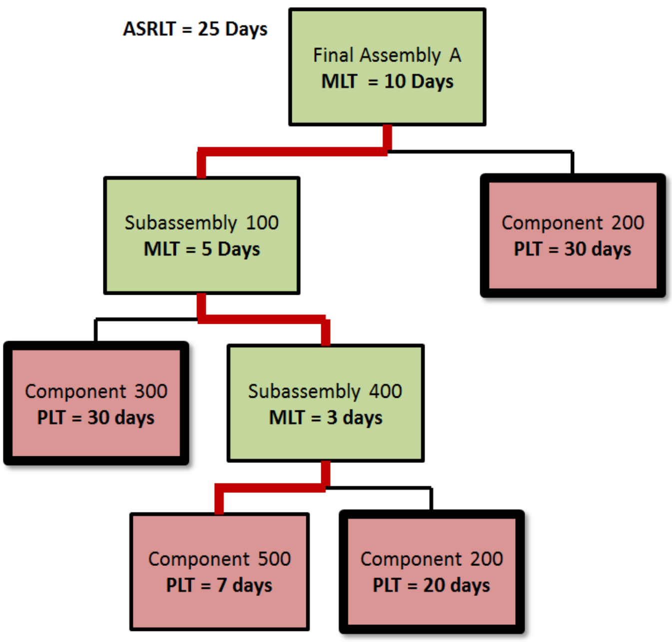


Figure 6: Example ASRLT of final assembly A

The ASRLT is the central principle of DDMRP implementation and it is used in combination with *"Matrix BOM"* to evaluate where to position or not to position inventories in the supply chain (Ptak & Smith, 2011, pp. 395-396). Matrix BOM is *"a chart made up from 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"* (APICS, 2008, p. 82; Ptak & Smith, 2011, p. 396). Purpose of Matrix BOM is to find inventory leverage points by comparing BOMs of different parent level items by looking at whether there exist shared components which could be potential items to be stocked in order to reduce lead time, or stock level, of parent level item. Primary focus is to find shared components which belong into ASRLT paths of multiple parent items since these are likely to yield highest benefits in lead time and inventory reduction (Ptak & Smith, 2011, p. 401). If parent item is stocked then primary objective is to decrease required inventory, if parent is non-stocked then objective is lead time reduction and increasing of market responsiveness. To get an answer on "*how much the buffering yields benefits"* the matrix BOM is used by following four step process summarized in Table 1 below.

Table 1: Process of evaluating benefits of inventory positioning

Step	**Parent is stocked**	**Parent is non-stocked**
1	Starting ASRLT of parent	Starting ASRLT of parent
2	Average on-hand inventory calculated with starting ASRLT of parent	New ASRLT after inventory positioning and amount of time reduction achieved
3	New ASRLT after inventory positioning and amount of time reduction achieved	Potential market impact what new ASRLT enables to achieve
4	Inventory investment needed for new ASRLT (calculated with average on-hand position)	Inventory investment needed for new ASRLT (calculated with average on-hand position)

Also other alternative definitions can be found from supply chain literature for the whole cumulative manufacturing lead time (CLT) and for the longest unprotected path referred in DDMRP as ASRLT. Mather (1988) and Sharman (1984) made similar classification of lead times popular in the field of logistics by separating **delivery lead time** from the **production lead time** where delivery lead time represents the full realistic lead time required for delivering the product to customer while production lead time indicate the full manufacturing lead time required for producing the product. This separation is used on strategic and higher level of supply chain design in concepts of:

decoupling point (DP) (Hoekstra & Romme, 1992; van Donk, 2001), *order penetration point (OPP)* (Sharman, 1984; Olhager, 2003) and *customer order decoupling point (CODP)* (Olhager, 2010). Similar separating point between make-to-stock and make-to-order manufacturing strategies is referred with terms such as *push-pull boundary* (Simchi-Levi, et al., 2008), *inventory-order interface* (Hopp & Spearman, 2011) and in *lean versus agile* literature (Naylor, et al., 1999; Childerhouse & Towill, 2000; Christopher, et al., 2006).

Difference between DDMRP theory (Ptak & Smith, 2011) and previous supply chain literature (Sharman, 1984; Mather, 1988; Hoekstra & Romme, 1992; Olhager, 2003; Simchi-Levi, et al., 2008; Hopp & Spearman, 2011; Childerhouse & Towill, 2000) is that DDMRP goes into more concrete level into details of material planning and control by using BOM structures as a basis for analysing the decoupling points within the production process. Another difference is that DDMRP inventory positioning process focuses only on vertically integrated supply chains by making the distinction of parts into make and buy categories, where the BOM analysis is used only on make parts. The previous decoupling point literature takes more strategic perspective and is mainly concerned on designing the higher level product delivery strategies by using the decoupling point as the main factor for the selection of product delivery strategy (Olhager, 2003). In this study the strategic level – and across enterprise boundaries exceeding – theories needs to be included in the first component of DDMRP implementation because the scope of this study is to consider how DDMRP could be implemented in non-vertically integrated supply chains, meaning going into details of the BOM structures of purchased parts. The model of Jan Olhager (2003) is selected for this purpose to be used for designing the optimal customer-order-decoupling-point (CODP) and product delivery strategy for purchased parts.

From manufacturing system perspective the DDMRP system is eventually one application of *"constant work in process"* system, often referred as *"CONWIP"*, where the consumption in downstream inventory position authorize replenishment order to be manufactured from upstream inventory position (Hopp & Spearman, 2011, pp. 363-364). The basic logic in inventory positioning and management should in theory remain same despite the demand and replenishment is generated inside one company or between inventory positions owned and managed by different companies. In reality there is significant difference whether the inventory positions is inside one company or between different companies. When the inventory is managed inside one company the orders can be triggered out from the inventory position much faster since the inventory is optimized and managed for the single company. When the source inventory position for replenishment order is owned by another company the consumption, manufacturing or replenishment of part from the source inventory position is not necessarily triggered as fast as it could be due various reasons including order backlogging and demand smoothening. In this paper this source inventory position outside company boundary is referred as a *"customer order decoupling point"* (CODP) according to Olhager (2010).

CODP is the point from where the products are made according to customer order and often the general advice is that supply chains in upstream and downstream of this point should operate with different material management principles (Sharman, 1984; Olhager & Östlund, 1990; Olhager, 2003; Olhager, 2010). The upstream part of CODP is referred as make to order (MTO) chain and is advised to be managed with pull system based on customer orders. The downstream part is generally referred as make to stock (MTS) chain where the common proposal is to perform inventory management based on planning and forecasts and hence manage the chain with push system principles. (Hoekstra & Romme, 1992; Mason-Jones, et al., 2000; Olhager, 2003; Simchi-Levi, et al., 2008; Olhager, 2010). Sharman (1984) introduced the CODP in logistics context (Olhager, 2003) with name of order penetration point by stating that "*in most cases, the order penetration point is where product specification gets frozen"* and that *"it is also the last point at which inventory is held".* Another widely referred definition of CODP came from Hoekstra and Romme (1992) with explanation that *"the decoupling point is the point that indicates how deeply the customer order penetrates into the goods flow".* Hoekstra and Romme (1992) propose five generic CODP position alternatives as the *"five basic logistic structures"* for defining the order-delivery strategy of the supplying company. These five basic structures are illustrated in Figure 7 below with explanation what are the alternative order delivery strategies of the suppliers of case company Wärtsilä.

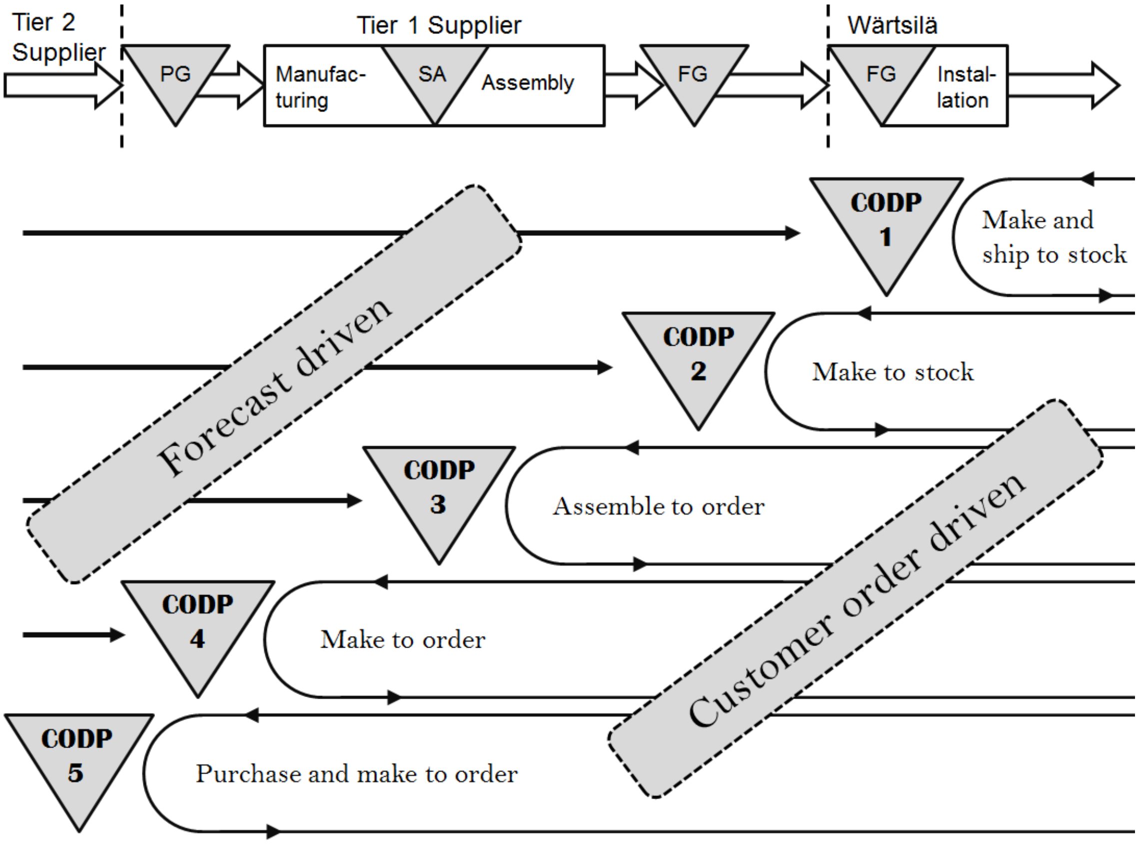


Figure 7: Alternative CODPs (Hoekstra & Romme, 1992; Olhager, 2003)

Olhager (2003) divides the CODP positioning decision into three main categories what to consider when creating optimal CODP position decision for supply chain. These main categories are: (1) Demand, (2) Product and (3) Production characteristics where each of these characteristics contains multiple different factors which affect into the main characteristic. The characteristics and contributing factors are presented in Table 2 below.

Table 2: Factors affecting the positioning of the CODP (According to Olhager, 2003)

Demand characteristics	**Product characteristics**	**Production characteristics**
Delivery lead-time requirements	Modular product design	Production lead time
Product demand volatility	Customization opportunities	Number of planning points
Product volume	Material profile	Flexibility of the production process
Product range and product customization requirements	Product structure	Bottleneck of the production process
Customer order size and frequency		Sequence-dependent set-up times
Seasonality of demand		

The three main characteristics are directly and indirectly impacting to the positioning of CODP. A major contribution comes from the relationship between two factors: delivery lead time and production lead time, which both are outcome of the three major characteristics: demand, product and production. The delivery lead time means customer tolerant lead time which is illustrated as the outcome of demand and product characteristics. The production lead time is the time from issuing a production order until the product is produced, and this time is illustrated as the outcome of product and production characteristics. The delivery and production lead time forms a “P/D ratio” which indicates how much longer or shorter the production lead time is compared to delivery lead time. “*A conceptual factor impact model”* which shows the connections between three characteristics and CODP positioning decision is presented in Figure 8. (Olhager, 2003).

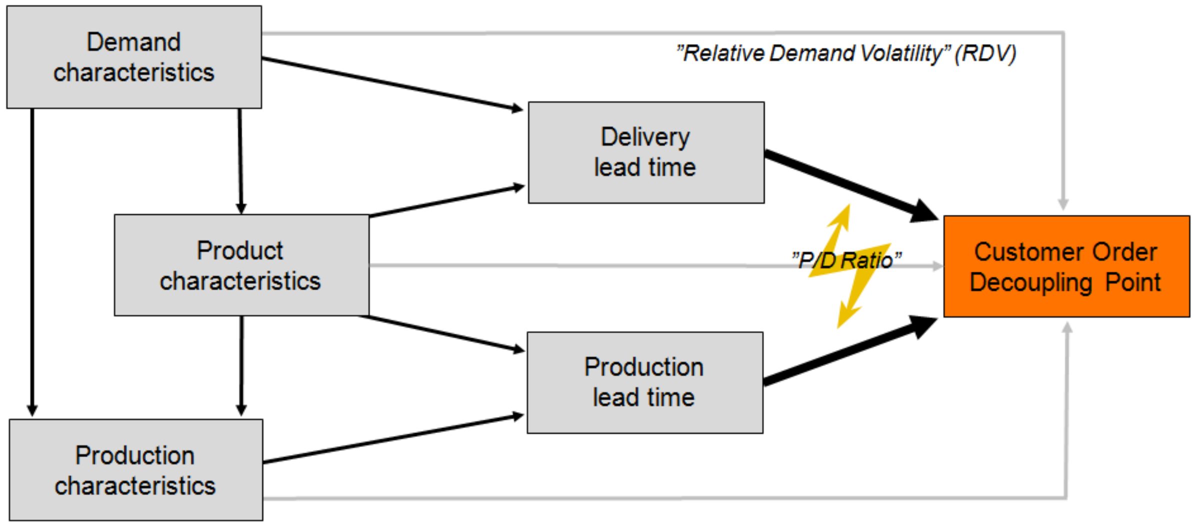


Figure 8: Conceptual factor impact model (Olhager, 2003)

The decision making model of Olhager (2003) is based on two factors which are placed in a diagram which gives proposal on optimal product delivery strategy. The factors used in the model are demand volume and volatility indicated with *relative demand volatility* (RDV). RDV is compared to *production to delivery lead time ratio* (P/D ratio) which implies if the *production lead time* is higher or lower than customer tolerance time defined as the *delivery lead time*. RDV is scaled from low to high where the values of high and low dependent on the context where different product market combinations are analyzed. P/D ratio is divided into two main segments depending if the value of P/D ratio is below or above 1, i.e. if the production lead time is higher or lower than delivery lead time. (Olhager, 2003).

The model is presented in Figure 9 and it is divided into four quadrants. The first two quadrants are easiest to manage and design because in both cases the CODP positioning decision is mainly dependent on the production optimization to yield most cost efficient supply chain. In both of these cases the production lead time is less than the delivery lead time resulting into P/D ratio below 1, when the time required for producing the whole product is less than what customer is willing to wait. The two remaining quadrants have more limited options to pursuit since in these cases the production lead time is higher than delivery lead time which creates pressures for manufacturer to be capable to deliver products within the time frame what customer is tolerant to wait. (Olhager, 2003).

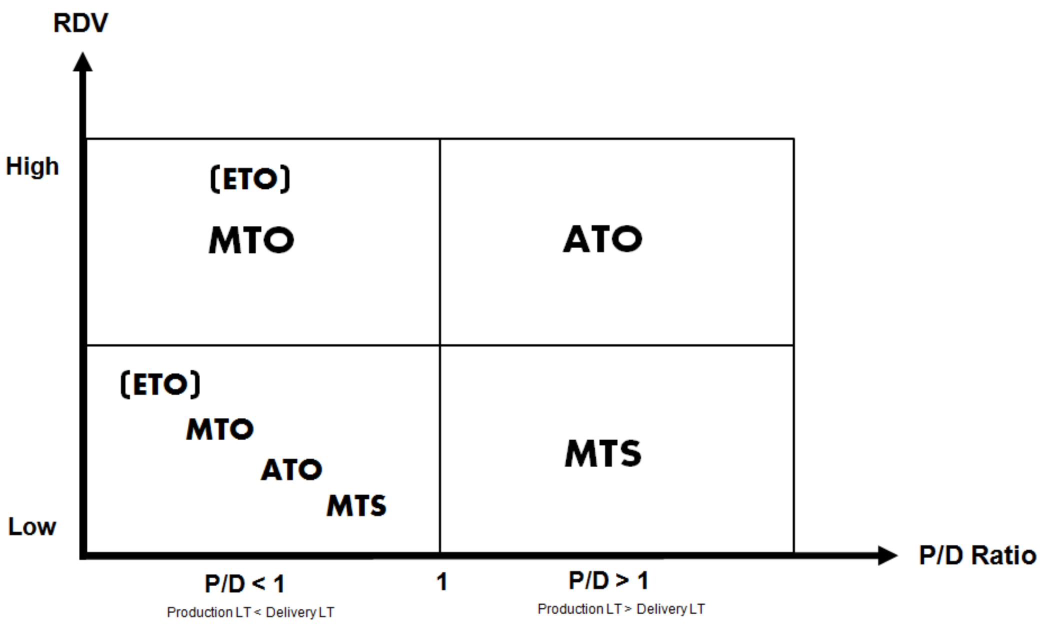


Figure 9: A model for choosing the right product delivery strategy (Olhager, 2003)

The first quadrant with low RDV and P/D less than 1 the company is in most favored situation where all of the four different product delivery strategies are possible to implement. Despite all of the possible CODP positions and respective product delivery strategies are possible to carry out within the delivery lead time companies may want to utilize different strategies for different products. Example MTS policy is favored option for very low RDV products since it enables an economies of scale to be achieved even though the products could be produced to order with MTO strategy. (Olhager, 2003).

The second quadrant with high RDV and P/D less than 1 the MTO or ETO strategy is often the most favored option. MTS strategy could be applied just like within the first quadrant but due to high demand volatility the amount of stock keeping units would become really high leading to high inventory holding costs (Olhager, 2003). In order to decrease inventory holding costs and mitigate risk of stock obsolescence (Hoekstra &

Romme, 1992) company might want to push CODP downstream which would enable MTO or ETO strategy (Olhager, 2003).

In the third quadrant with low RDV and P/D ratio higher than 1 the MTS is the most feasible strategy to be chosen. MTO or ETO strategies are impossible to conduct within the delivery lead time because the production lead time is longer than delivery lead time (Olhager, 2003). ATO strategy is possible also in low RDV scenarios if the product structure and production process enables ATO delivery strategy but in order to stabilize the demand variability in production process and so on enable higher efficiency companies might want to select MTS strategy (Olhager, 2003). For low RDV products the MTS strategy improves responsiveness to customer order and dampens variability from production process which creates the production planning and optimization easier which might enable economies of scale to be achieved. In the other hand the cost of holding this stock in MTS position is relatively low since the demand is stable and the required stock levels in future are easier to forecast. Also the risk of stock obsolescence becomes low since the products are consumed on regular basis from the MTS position which results into good inventory turn-over ratios.

In the fourth quadrant where RDV is high and P/D ratio is higher than 1 there exists similar situation as within third quadrant where MTO and ETO strategies are impossible to select in order to be capable to satisfy customer tolerant delivery lead time. Because the demand uncertainty (RDV) is high the MTS strategy would become expensive solution to pursuit due to high level of inventories required in MTS positions (Olhager, 2003) combined with high risk of stock obsolescence (Hoekstra & Romme, 1992).

If the product is located in the fourth quadrant the most feasible solution is to pursuit ATO strategy where the production process is decoupled with CODP into two parts where the upstream would operate according to MTS strategy and downstream would operate according to MTO strategy. Critical restriction for the position of CODP is that MTO is possible for downstream only if it can be conducted within delivery lead time. In the end the actual production lead time will not decrease below the delivery lead time but the lead time what customer sees with the orders placed to supplier is only the time what it takes to assemble the product to customer order from the decoupling point. So from the customer perspective supplying company do have a shorter production lead time than delivery lead time because it is capable to make the products from the CODP below or within the delivery lead time (Olhager, 2003). In Figure 10 is illustrated how a company can use ATO strategy for decoupling the production process into two parts: MTS for pre-CODP operations and MTO for post-CODP operations.

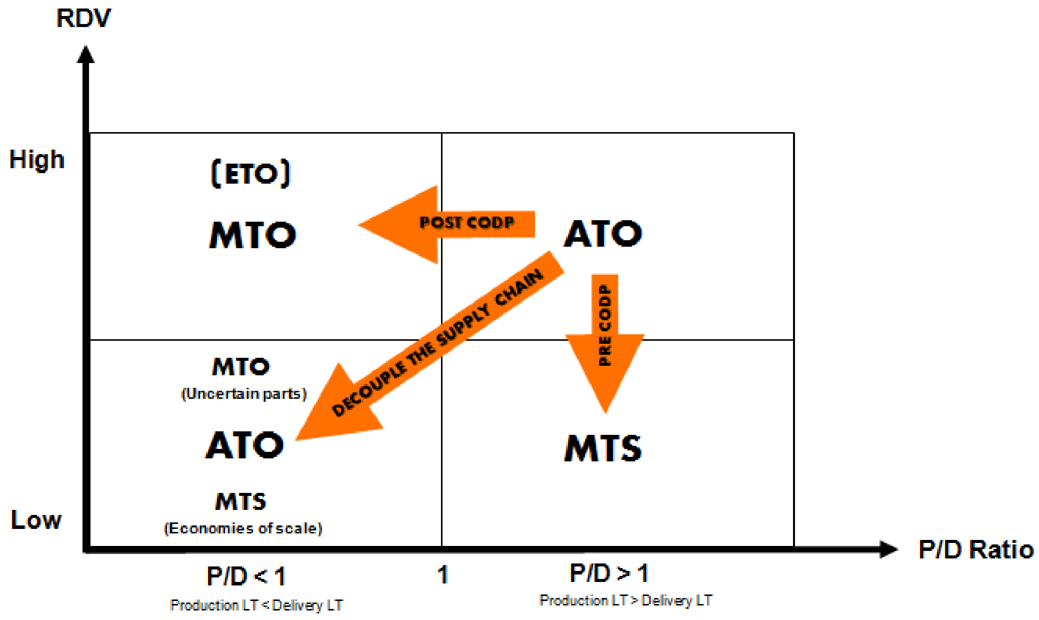


Figure 10: Decoupling ATO into MTS for pre-CODP operations and MTO for post-CODP operations (Olhager, 2003)

In the end all of the supply chains have P/D ratio higher than 1 if the chain is looked from end-to-end perspective all the way from raw materials to ultimate end-customer because the time required for the whole supply chain is always longer what the end-customer is willing to wait, it is just a matter of perspective which part of the supply chain is considered. Because all of the parties involved in the chain should be willing to satisfy the customer demand of their direct customers there must exist customer-order-decoupling-points between each company in the chain. With the model by Olhager (2003) companies can identify how their CODP should be positioned on strategic level which determines what product delivery strategy should be utilized for different product market combinations. When the high level strategies are identified then the detailed BOM analysis explained in DDMRP theory (Ptak & Smith, 2011) can be used on part level on defining which parts to buffer with inventory and manage as *strategically replenished parts,* and which parts to buffer with time and manage as *lead time managed* (LTM) parts. Following chapters explain how to identify and define buffer profiles with DDMRP theory per each item in the BOM. As a rule of thumb the upstream supply chain of CODP is advised to be managed with replenished parts while the downstream supply chain of CODP is most suitable to be managed with lead time managed parts.

2.2.2 Component 2: Buffer profiles and levels

After defining the strategic decoupling points and inventory positions in the supply chain starts the process for setting the rules on how these decoupling points are managed. In DDMRP this process is referred as *"buffer profiles and level determination"*. The buffer *profile* determination is a process where materials, parts and end-items are grouped according to four critical factors. In the buffer *level* determination these factors are used to calculate color coded *"buffer zones"* which are used in planning phase to manage the inventory levels for each strategically decoupled item. (Ptak & Smith, 2011, pp. 406-407). The four factors which define the buffer profiles and zones are:

Factor 1: Item type indicate whether the decoupled item is manufactured (M), purchased (P) or distributed (D). Reason for grouping items in these three groups is due to the different lead time horizons between the groups where "short" one week lead time of purchase part would not necessarily be "short" lead time for manufactured part. Another reason is to gain control on the full chain and not just for one item type. (Ptak & Smith, 2011, p. 407).

Factor 2: Variability is segmented into three groups: high, medium and low and is analyzed from supply and demand perspectives. In table 3 below is presented how the segmentation for both supply and demand variability can be done when defining heuristically the variability factor for each part or SKU from different item type categories. (Ptak & Smith, 2011, p. 408).

Table 3: Supply and demand variability segmentation

	High	**Medium**	**Low**
Supply variability	*"Frequent supply disruptions"*	*"Occasional supply disruptions"*	*"Reliable supply (either a highly reliable single source or multiple alternate sources that can react within the purchasing lead time"*
Demand variability	*"Subject to frequent spikes"*	*"Subject to occasional spikes"*	*"Little to no spike activity – its demand is relatively stable"*

Factor 3: Lead time is categorized into three groups: short, medium and long. Again it is important to cluster lead times separately per each item type – *purchased (P), manufactured (M) and distributed (D)* – since the comparison between example manufacturing lead time and delivery lead time of purchased part wouldn't give relevant results since manufacturing lead times are measured in hours while purchasing lead times can be measured in days, weeks and months. By clustering the lead times separately per each item type it is possible to gain relevant groups for each item type. When clustering the purchase items the ones with couple of days lead times can be left out from the analysis since little or no benefit can be gained from DDMRP implementation for such items. The example used in book contained only purchase part where lead time ranged between 3 and 56 days. When clustering manufactured items the ASRLT is suggested to be used instead of CLT or MLT because often the CLT is overestimation and MLT is underestimation of actual lead time. The exact boundaries for short, medium and long lead times are not given in DDMRP theory but it is suggested to consider the boundaries case-by-case according to the environment and company where DDMRP is implemented. (Ptak & Smith, 2011, pp. 409-410).

Factor 4: Significant Minimum Order Quantity (MOQ) means situation where exists certain limitations for the batch size to be used for buffer replenishment. In some cases these limitations can be reconsidered and eliminated while in some cases there are valid reasons for having certain minimum, maximum or fixed batch size. Example for the purchase items the MOQ limitation can be set due to delivery restrictions while for the manufacturing items it can be defined due to minimum required batch size required for an efficient production run. In some cases these limitations can be set due to optimization of transportation or production costs when it becomes feasible to evaluate tradeoff what would be achieved in lowered inventory holding costs if the MOQ limitation could be reduced or eliminated. The question of whether the MOQ is significant depends on the results of buffer zone calculation and from the size of green zone. (Ptak & Smith, 2011, p. 410). Below in Table 4 is presented an example overview which could be used for each item and SKU when identifying in which groups it would belong to in respect to all three factors described above where the components with MOQ can be "earmarked" by adding text "MOQ" in the buffer profile.

Table 4: Buffer profile combinations (Ptak & Smith, 2011, p. 412)

		Manufactured = M	Purchased = P	Distributed = D		
Variability		M10	P10	D10		Lead time
	Low = 1	M11	P11	D11		
		M12	P12	D12		
		M20	P20	D20	Short = 0	
	Medium = 2	M21	P21	D21	Medium = 1	
		M22	P22	D22	Long = 2	
		M30	P30	D30		
	High = 3	M31	P31	D31		
		M32	P32	D32		
		M10 MOQ	P10 MOQ	D10 MOQ		
		M11 MOQ	P11 MOQ	D11 MOQ		
		M12 MOQ	P12 MOQ	D12 MOQ		
		M20 MOQ	P20 MOQ	D20 MOQ		
	MOQ Application	M21 MOQ	P21 MOQ	D21 MOQ	MOQ Application	
		M22 MOQ	P22 MOQ	D22 MOQ		
		M30 MOQ	P30 MOQ	D30 MOQ		
		M31 MOQ	P31 MOQ	D31 MOQ		
		M32 MOQ	P32 MOQ	D32 MOQ		

After correct buffer profiles are identified for each strategically managed part, starts the buffer zone calculation. In DDMRP the strategic decoupling buffers, both lead time managed and replenished parts, are divided into three basic color coded zones – green, yellow and red – which are used for controlling and monitoring the buffers. Green zone indicates situation where no actions are needed, yellow zone means rebuilding or replenishing the buffer and red means that buffer may require special attention. In addition to these three basic zones there exist two additional zones – light blue and dark red – which do not effect to buffer calculation but are used for improving buffer monitoring and priority setting. Light blue indicate over top of green (OTOG) situation where too much of material is supplied to buffer position and dark red indicate a situation of stock out with demand (SOWD). (Ptak & Smith, 2011, pp. 412-413). Purpose of the buffer zones is to help companies to use their inventories as an asset instead of liability with an improved visibility and priority setting through color coding system. This means that instead of oscillating back and forth between too little and too much, companies could manage their inventories in optimal range and at the same have visibility whether the inventory level is in danger to either grow or decrease too much than is needed.

Calculation of buffer level is done by defining green, yellow and red zones, which in together determine the *"top of green"* (TOG) level which is the maximum buffer level. All of the zones depend on the *"average daily usage"* (ADU) and ASRLT of component. Yellow zone is easiest and equals the ADU over ASRLT. Green zone is calculated similarly but includes also the *"lead time factor"* determined by planning team. If the calculated green zone is less than MOQ then green zone is defined as the MOQ and hence the calculated green zone defines if the MOQ is significant or not. Green zone also defines average order frequency since the replenishment order is generated when the calculated "*on-hand position"* goes below green zone when the average frequency is equal to green zone divided by ADU. Red zone is summary of two parts: red zone base and red zone safety. The base level is calculated in similar way as the green zone and safety level is calculated by using variability factor defined by planning team. Below in Table 5 is presented recommended impact ranges to be used as lead time and variability factors in buffer zone calculation. Previously established buffer profiles, Table 4, describes where lead time and variability group the component belongs. Question about what exact percentage should be used for each part is not given in DDMRP theory but is proposed to be considered based on how much safety the planner is willing to have for each buffered part. (Ptak & Smith, 2011, pp. 414-422)

Table 5: Variability and lead time factor ranges

Variability Factor Range	
High Variability	61-100% of Red Base
Medium Variability	41-60% of Red Base
Low Variability	0-40% of Red Base
Lead Time Factor Range	
Long Lead Time	20-40% of ADU over ASRLT
Medium Lead Time	41-60% of ADU over ASRLT
Short Lead Time	61-100% of ADU over ASRLT

Similar approach to variability categorization, and its implications to required safety stock levels, is considered in Dell Inc's supply chain where the supply variability defines *"supplier handicap"* level which affects to the target inventory levels in Dell's *"revolvers"* (Kapuscinski, et al., 2004). These *revolvers* are special vendor-managed-inventory (VMI) arrangements located in jointly owned warehouses close to Dell's assembly plants where the supplier is responsible for inventory replenishment to fulfill the target inventory level defined by Dell's assembly plant. Since Dell noticed significant difference between suppliers performance to fulfill the defined target inventory levels they designed, in cooperation with *Tauber Manufacturing Institute*, supply and demand variability factors which contributes to the target level calculation by adjusting the levels according to defined *"handicap"* levels by using golf analogy in explaining the logic of the factors affecting to the required safety stock level. (Kapuscinski, et al., 2004).

The *supplier handicap* level is defined by calculating replenishment time variance together with *"par"* inventory level which is required to run the system without any variability in the system. The *par* level is calculated by using three factors: demand, replenishment time and shipping frequency. In addition to *supplier handicap* also *"Dell's handicap"* is defined to be taken into consideration. *Dell's handicap* is determined by the demand variability caused by Dell's assembly plant and it is measured by using forecast error and pull variance. The purpose of this variability segmentation into supplier and Dell's handicaps is to create visibility on the sources of both demand and supply variability which together affect into required safety level in revolver. The elements of the inventory breakdown in the developed model are presented in Figure 11 below. (Kapuscinski, et al., 2004).

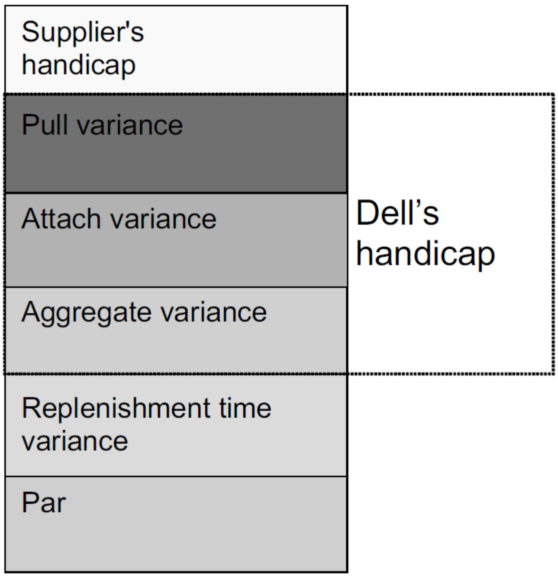


Figure 11: Total inventory breakdown in Dell's revolver (Kapuscinski, et al., 2004)

2.2.3 Component 3: Dynamic adjustments

Most of the current manufacturing environments are subject to constant changes in markets where to operate with different products, in materials to be used for the different products, in suppliers which to supply components, in manufacturing capacity and in methods used for producing the products. Because all of these factors are not static over time and those have direct connection into the buffer zone calculation the DDMRP system includes dynamic adjustment feature. Purpose of dynamic adjustment is to enable the system to adapt the defined buffer levels and hence enable optimal working capital utilization in the dynamic environment. The dynamic adjustment in DDMRP system contains three different types of adjustments called ***recalculated adjustments***, ***planned adjustments*** and ***manual adjustments***. (Ptak & Smith, 2011, p. 423).

The ***recalculated adjustment*** can be automatized into the system depending on the capabilities of the planning system where DDMRP is integrated. The recalculated adjustment can be done in two ways: either by using *"average daily usage (ADU)-based adjustments*" or by using *"zone occurrence-based adjustments"* where the ADU-based adjustment is the recommended solution. In ADU-based adjustment the past consumption of stock keeping unit (SKU) is recalculated by using rolling time horizon where the frequency of usage does not necessarily need to be based on average daily usage (ADU) even though it is the most often used solution. Also the length of the horizon is environment specific where example 3 months horizon might be suitable for one company while 12 months might be more favored for another. If the length is too short the system becomes over-reactive and with too long horizon the system becomes under-reactive. Because also SKUs inside one company and environment behave differently there most probably is not a *"one size fit all*" length for the rolling horizon which is the reason why alerts and early warning indicators described with the ***manual adjustments*** are used for monitoring if some of the SKUs behave either under- or over-reactive.

In the occurrence-based calculation the buffer adjustment is made according to the number of occurrences of replenishment order generation for certain SKU. In occurrence-based adjustment there is defined average order interval for a part based on the demand and lead time profile and if the occurrence is not according to the average frequency then adjustment is made for the buffer profiles. Example if there are multiple red zone replenishments or a stock outs then the assumption is that the size of a buffer is too small and increase adjustment is needed. Similar way if the inventory position is too long in the green zone during the defined interval the assumption is that the buffer size is too much and decrease is needed. The problems with occurrence-based adjustment are the challenge to define what the number of too many occurrences should be, what should be size of an interval and what size of adjustment should be made based on the occurrences. Since the answering for these questions is highly dependent on the planner experience and intuition the ADU-based adjustment is preferred alternative. In Figure 12 is presented an example illustration of the ADU-based recalculation with 3 month rolling adjustment where the available stock position (on-hand + open supply –

qualified demand) is presented with black line and ADU with a blue line. (Ptak & Smith, 2011, pp. 424-425).

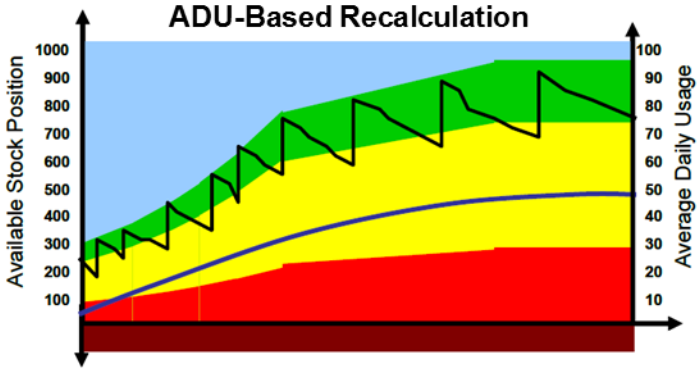


Figure 12: Recalculated ADU-based adjustment (Ptak & Smith, 2011, p. 424)

*"The **planned adjustments** are based on certain strategic, historical and business intelligence factors"* (Ptak & Smith, 2011, p. 425) where the size of the buffers is manipulated by using information available about significant changes in demand due to seasonality, marketing campaigns or changes in product mix. In case of seasonal demand, or expected impact of marketing campaign to increase demand, the buffer size can be adjusted in advance by using the ASRLT of replenishment order together with forecasted ADU over the length of ASLRT. Figure 13 illustrates this method where the buffer is adjusted by calculating the recommended buffer sizes by using the forecasted ADU in the time of current date plus ASRLT. Figure 14 illustrates three typical changes in product mix including product ramp-ups, ramp-downs and transitions from one variant to another. In case of changes in the product mix the DDMRP uses planned adjustment factor (PAF) which is a given percentage what affects into ADU used for buffer zone calculation. (Ptak & Smith, 2011, pp. 425-432).

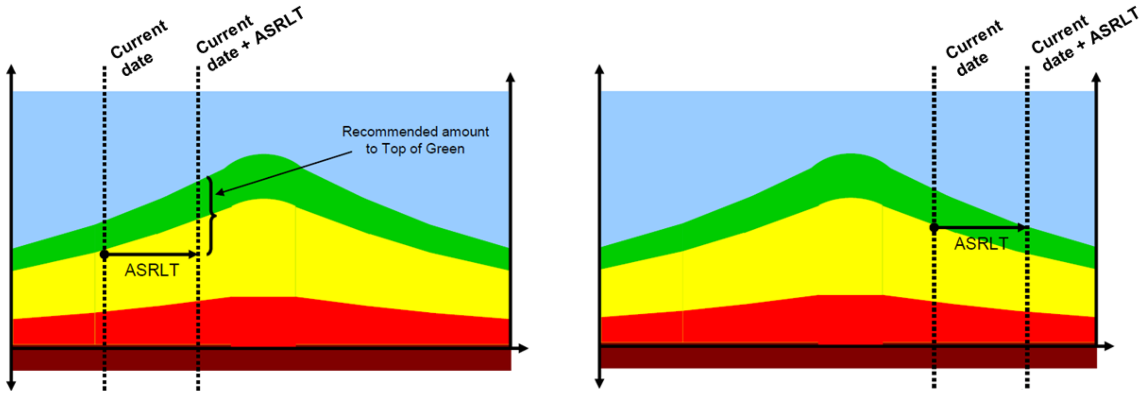


Figure 13: Seasonality (Ptak & Smith, 2011, p. 426)

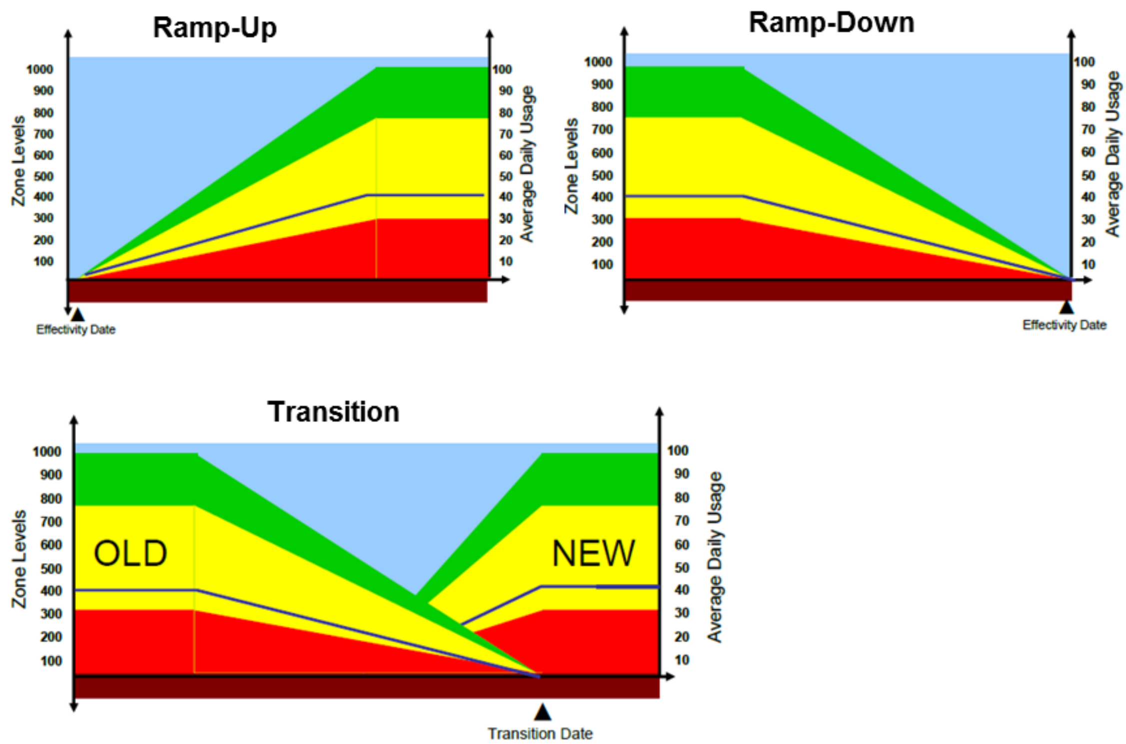


Figure 14: Changes in product mix (Ptak & Smith, 2011, pp. 430-431)

Manual adjustments are done by using the alerts that are used for giving a visibility on how buffers are performing in respect to the defined buffer zones. Manual adjustments can be used to support recalculated adjustments by giving for the planners warnings if there is significant change in demand for which the defined rolling ADU calculation cannot react fast enough. For this purpose *"ADU alert"* gives an indication for planner if there have happened significant change in ADU in shorter time frame than the rolling zone of recalculated adjustment. Parameters of *ADU alert* are determined with *"ADU alert threshold"* and with *"ADU alert horizon"*. *ADU alert threshold* defines what level of change in ADU is classified as significant enough for an *ADU alert*. *ADU alert horizon* is the defined length of time horizon for which the *ADU alert threshold* applies and it is usually defined to be less than the rolling horizon used in ADU-based recalculated adjustment. (Ptak & Smith, 2011, p. 433).

2.2.4 Component 4: Demand driven planning

According to "*fundamental distinction between push and pull systems"* of Hopp & Spearman (2011, p. 369) the conventional MRP can be considered as push system and DDMRP as the pull system. Hopp & Spearman (2011, p. 369) defines the difference between push and pull by making generalization that *"push system control throughput and observe WIP"* while in contradiction *"pull system control WIP and observe throughput"*. The conventional MRP tries always to match the available stock according to the demand defined in the master production schedule (MPS). MPS is based on customer orders as long as there is enough order backlogs in the order book to cover sufficient planning horizon. If there is no actual demand in the MPS the customer orders can be replaced with forecasted customer orders to overcome the lack of demand signals in the planning horizon. If there is no actual or forecasted demand in the MPS for independent demand items, then there is no demand for any dependent demand items in the system. In this situation the MRP will not generate replenishment orders and tries to get rid of existing orders and inventory because the MRP is not designed to keep any available inventory on-hand or in pipeline, except the defined safety stock inventory level.

In MRP safety time and stock levels, which usually are static and doesn't affect to the available stock calculation, are used to overcome the demand and supply uncertainties occurring in supply chain. The difference in DDMRP is that the inventory can be replenished despite there would not be demand for a single part in MPS because the DDMRP tries to keep constant work in progress available in the system according to defined buffer levels. Another difference is that the safety levels in MRP don't change unless someone changes the determined safety level. In DDMRP the safety stock is included in the red zone designation which is adjusted by using the *planned adjustment factors* (PAF). In addition to PAF the DDMRP adjust the available stock level calculation if there occurs qualified demand spikes in the planning horizon. (Ptak & Smith, 2011).

For the replenished parts the DDMRP doesn't need to have extended MPS planning horizon since the system ignores all of the future planned demand in the system, except the qualified spikes in the order spike horizon, and concentrates on monitoring the WIP levels instead of the planned throughput level. The WIP level is monitored with the available stock equation: *on-hand inventory + on-order inventory – sales order demand* (Ptak & Smith, 2011, p. 413), where from the sales order demand is taken into consideration only the demand due today and past due demand. The calculation logic itself is a kind of CONWIP application with an order-up-to rule where the consumption from the inventory position authorizes replenishment order generation to upstream chain. Rather similar CONWIP application and stock calculation method is used in the *"APIOBPCS Decision Support System"* described by Zhou, Disney and Towill (2010) which is similar variant of the order-up-to rule as the DDMRP planning method with two feedback controls on WIP levels in the **on-hand inventory** and the **orders-in-pipeline inventory**.

Despite much of the attention in DDMRP theory is given for stocked and "*strategically replenished*" parts, this is not the only part type where to apply DDMRP method likewise not all of the stocked parts are feasible to manage with DDMRP method. All of the parts required for running manufacturing operations can be classified into two main categories of *stocked* and *non-stocked* items. In DDMRP the stocked items are classified into three sub-categories referred as the *replenished parts, replenished override (RO) parts* and *min-max parts, w*hile the *non-stocked* parts are classified into two sub-categories of *lead time managed (LTM) parts* and *non-buffered parts*. Figure 15 illustrates the part categories in DDMRP where the yellow boxes are classified as *strategically positioned and managed parts* where the DDMRP buffer management system is applied. The grey boxes are classified as non-strategic parts which can be managed with conventional inventory management systems. (Ptak & Smith, 2011, pp. 435-439).

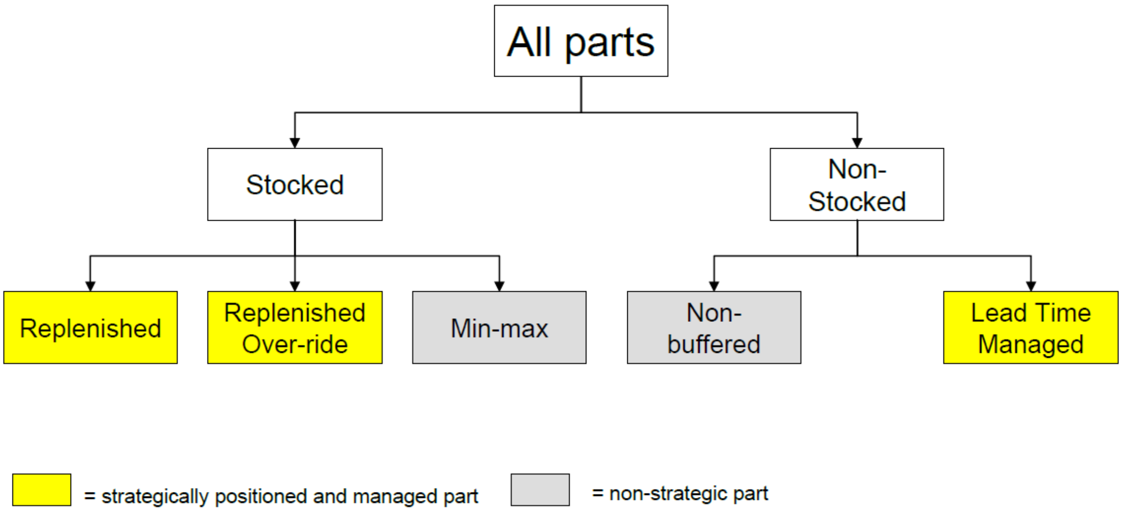


Figure 15: Part categories in DDMRP (Ptak & Smith, 2011, p. 439)

The *replenished parts* are strategically positioned and selected items where buffers are managed by using the color-coded buffer zones together with DDMRP buffer management logic. *Replenished over-ride (RO) parts* are same way strategically positioned and selected as the *replenished parts* but with a difference that the size of buffer zones is fixed when also the dynamic adjustment feature is not applied. *RO parts* are often used in situations where there exist some certain limitations for the sizing of the buffer zones due to limitation in space where parts are stocked. The limitation of buffer zones is only way to keep on control that the physical limitations are not forgotten. *Min-max parts* are less strategically important replenished parts which can be managed with conventional *"re-order point"* inventory control mechanism where min level is the *re-order* point and max is the *"order-up to"* inventory level. In min-max system the replenishment order is recommended when the *on-hand* plus *on-order inventory* is below the min level where the size of the replenishment order is defined according to gap between min and max level.

Great proportion of all parts in manufacturing environment belong into *non-buffered parts* which are non-stocked items and can be managed with conventional MRP whenever there is demand for such items and as long as the parts are not strategically important. In DDMRP the non-stocked items require special attention due to strategic importance for the manufacturing of the product. These strategic non-stocked items are classified as *lead-time managed (LTM) parts*. The *LTM* parts are managed with similar kind of color-coded buffer zones as replenished and RO parts but with a difference that parts are make-to-order (MTO) instead of make-to-stock (MTS) parts. DDMRP uses time buffering for *LTM parts* instead of stock buffering used for replenished and RO parts. (Ptak & Smith, 2011, pp. 435-438).

The planning and replenishment order generation logic for replenished and RO parts in DDMRP is based on *"available stock equitation"* which is calculated with formula: "*on-hand balance + on-order stock – unfulfilled qualified actual demand"* (Ptak & Smith, 2011, p. 440). *On-hand balance* is the amount of materials physically available for use at the inventory. *On-order stock* is the total sum of replenishment orders generated but not yet received at the inventory. *Unfulfilled qualified actual demand* is based on the demand coming from actual customer orders – *not forecasted* – where only the orders due today, past-due orders and *qualified spikes* are taken into account. The qualified spikes are significant demand peaks from the customer orders which will be delivered in future. The demand is *qualified* by using *order spike horizon* and *order spike threshold. Order spike horizon* is the time horizon used for monitoring the future demand of SKU where the length of horizon is usually defined to be at least one ASRLT of SKU in the buffer. *Order spike threshold* is the limit of demand what is allowed to be in the horizon without being qualified as order spike which would affect into *available stock equitation* where the size of threshold is based on defined percentage from the size of red zone, typically 50% for replenished parts, and for min-max parts similar percentage of the minimum. The purpose of qualifying the order spikes is to limit the MRP nervousness in relation to future demand while at the same time take into account only the significant spikes in the demand which could predispose the buffer for a risk of stock-out if the spikes wouldn't be taken into account for replenishment order generation. (Ptak & Smith, 2011, pp. 440-441). For more detailed explanation on order spike horizon and threshold the reader is suggested to take a look on pages 442-446 from Ptak & Smith (2011).

The planning and order generation logic for non-stocked parts is based on back-scheduling of customer orders by using the lead times of parts in the BOM structure. Both lead time managed (LTM) and MRP managed parts generate supply order when there exist demand for respective parent level item which due date is used for calculating the planned release date for parts required to produce the final product. Difference between LTM and MRP managed parts is that in LTM there are inserted time buffers in the product structure to dampen the system nervousness and enable more reliable due date performance. Designing where to place time buffers is based on the BOM structure and into the longest unprotected path in the structure which is measured with and defined as the ASRLT. Time buffers are used to secure that ASRLT path is free from disruptions occurring in the legs, or in the feeding lines, of the BOM structure. In most cases the time buffering of shorter paths will not lengthen the delivery lead time of the final product because the ASRLT is the longest path. Figure 16 is an example make to order (MTO) product structure where the ASRLT path of 136 days is illustrated with blue bolded line. In this example ASRLT is equal to cumulative lead time (CLT) since there are no intermediate strategic buffers between the purchase part PPH and final product FPZ. CLT of each leg is illustrated with numbers with increased font while the numbers inside yellow boxes illustrate purchasing lead time (PLT) and inside light blue boxes manufacturing lead time (MLT) of each subassembly. (Ptak & Smith, 2011, pp. 447-454).

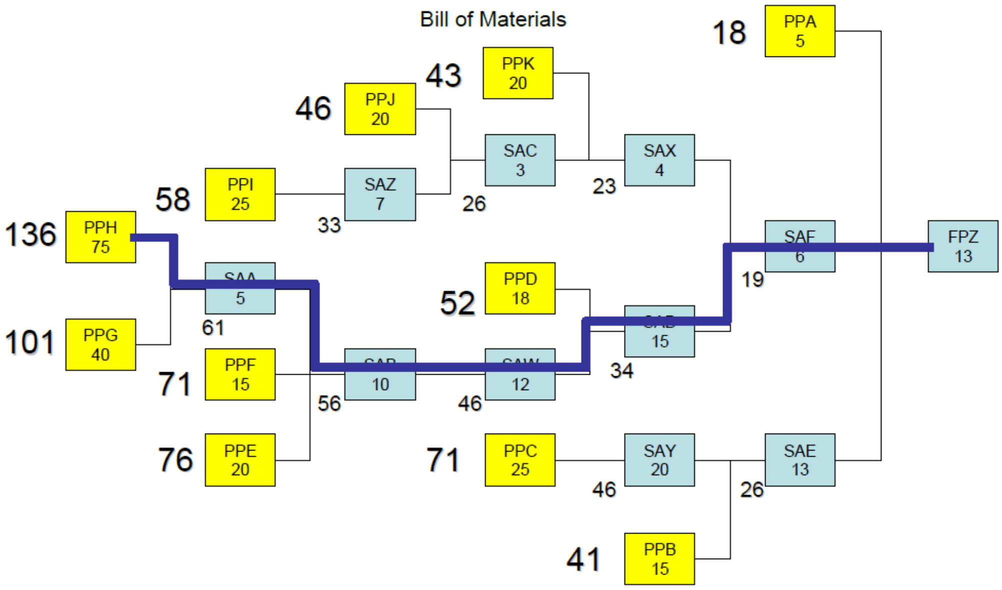


Figure 16: ASRLT in example MTO product structure (Ptak & Smith, 2011, p. 452)

To mitigate the system nervousness with the example MTO product there is needed some form of buffering. If the replenishment buffer, buffering with inventory, is not feasible solution due to example irregular demand of SKU or due to high level of customisation then the time buffering can become feasible alternative. In this example the time buffering of the shorter legs doesn't have effect on the delivery lead time of the end product FPZ if those time buffers are sized by using proposed one-quarter rule by Ptak and Smith (2011, p. 453). By following the one-quarter rule the time buffer is sized by using the ASRLT of the activity or path which is buffered. Example for purchase part PPE the size of the time buffer is 5 days which is 25% of the 20 days purchasing lead time, for sub-assembly SAE the size of the time buffer is 15 days which 25% of the 58 days lead time of longest path of SAE coming from 25 days of PPC, 20 days of SAY and 13 days of SAE. The time buffer is divided into three zones green, yellow and red where the size of each zone is one third of the time buffer, example for SAE each zone would be 5 days due since the size of whole buffer is 15 days. These zones are later on used for monitoring the due date performance of each leg in the chain where the purpose is to gain visibility on possible delays which would have effect on the ASRLT and due date performance of final product FPZ. Figure 17 below illustrates what the time buffering would look like within the example MTO product structure. Despite the legs of FPZ ASRLT would be buffered there is still risk for variability with the activities lying in the ASRLT path, example all of the subassemblies SAA, SAB, SAW, SAD, SAF, FPZ, which could delay the delivery of FPZ. To overcome the variability risk with these, the buffering with capacity in ASRLT path could be considered as an alternative for inventory and time buffering. (Ptak & Smith, 2011, pp. 447-454).

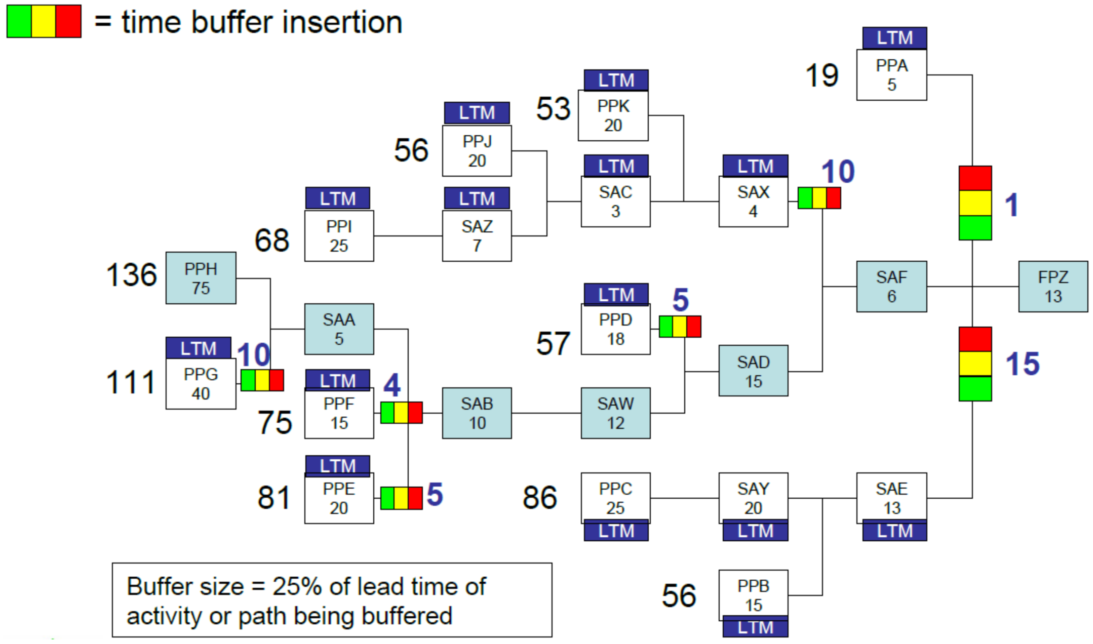


Figure 17: Time buffers in example MTO product structure (Ptak & Smith, 2011, p. 452)

2.2.5 Component 5: Visible and collaborative execution

MRP is a planning system which always needs certain execution system to set priorities for purchase orders (PO), transfer orders (TO) and manufacturing orders (MO), where the priority setting is usually based on due dates of released orders. Authors of DDMRP challenges this priority setting based on due date since it pushes organization to focus on due date performance which doesn't always correlate or support organization to maximize flow and ROI. Instead of focusing on due date performance the authors propose that material shortages should be the major performance indicator by using an example where on-time delivery can be 100% but still company can have material shortages which can stop the production, or cause stock-out in distribution chain, which will decrease company's capability to satisfy customers and generate more sales. For avoiding material shortages in the supply chain, the authors propose a set of execution alerts, Figure 18, which are used for monitoring the buffers and setting priorities for released orders. DDMRP execution alerts are divided into two groups where *buffer status alerts* are used for monitoring stocked parts and *synchronization alerts* are used mainly on non-stocked parts with an exception that *material synchronisation alerts* can be used also for stocked parts. (Ptak & Smith, 2011, pp. 457-461).

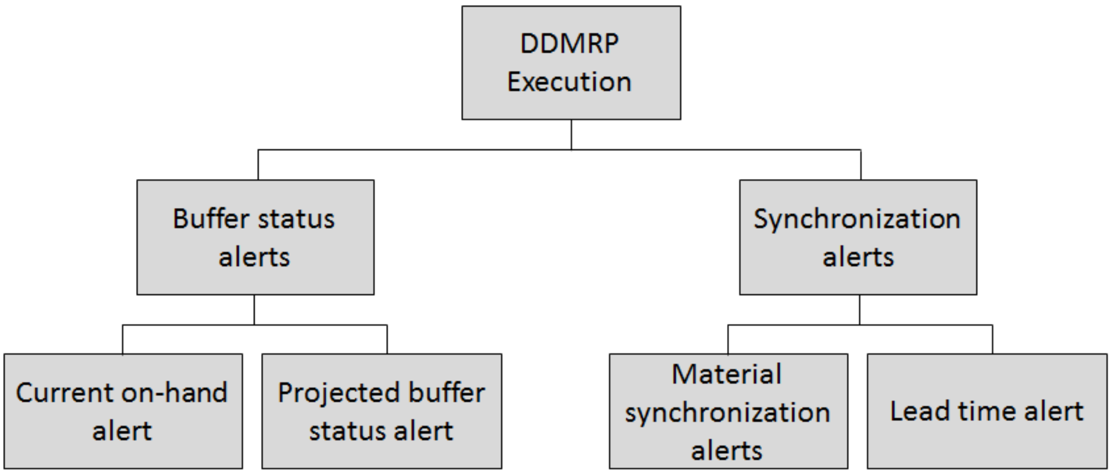


Figure 18: DDMRP execution alerts (Ptak & Smith, 2011, p. 461)

Buffer status alerts contain two types of alerts: *current on-hand alert* and *projected buffer status alert.* As the name indicates the *current on-hand alert* is used for monitoring the actual on-hand inventory status of replenished stocked items with a purpose to identify which open supply orders would require expediting by using color coding based on priority of expediting. Difference to conventional MRP rescheduling messages is that on-hand alerts provide priority for expediting when there is multiple orders to be expedited by indicating which parts requires most attention based on buffer on-hand statuses. *Projected buffer status alert* is used for proactive buffer status monitoring of replenished parts by using the average daily usage, actual demand and open supplies for gaining visibility over one ASRLT on possible future on-hand alerts. The difference between these two alerts is that current on-hand alert is giving warning and visibility on actual stock-out situations while projected buffer status alert is trying to avoid on-hand alert situations by providing proactively the visibility on buffer status in future and by giving suggestions which supply orders are in risk of causing stock-out situations. (Ptak & Smith, 2011, pp. 461-471).

Synchronization alerts consists two different alert types: *material synchronization alerts* which are used for non-stocked and stocked items, and *lead-time alerts* which are used for non-stocked. These alerts are based on due dates with a purpose to prevent potential delays caused by dependence between parts of sub-system and system itself. *Material synchronization alerts* (MSA) are used for all part types and the purpose of it is to show earliest negative on-hand position within minimum of one ASRLT future time horizon if the undelivered open supply order is going to arrive after demand date which creates negative on-hand position. In case of MSA planner needs to consider if the supply order can be expedited and is not then could the parent item be postponed to avoid delay caused by stock out with demand (SOWD) indicated by MSA. If the parent item is buffered with time, then minor postponements could be possible if the supply order cannot be expedited. These SOWD situations are usually caused by heavy sudden spike in demand, supply order has been confirmed for later date than where it was ordered or the parent level item is expedited to earlier due date than it was previously planned when supply order was released. (Ptak & Smith, 2011, pp. 471-474).

With stocked items some of the variation in supply and demand is prevented through the buffering with inventory but when the inventory is not feasible or possible to have then buffering with time becomes alternative solution against the variability. In DDMRP these non-stocked items buffered with time are called lead time managed (LTM) parts and for these parts is used *lead time alerts* for monitoring the system and for gaining visibility on possible problems with due dates of parts. Purpose of lead time alerts is to proactively monitor for possible problems before those become late deliveries and hence the using of these alerts leads to better due date performance with the critical non-stocked items. Below is presented an example LTM part where the total lead time of part is 63 days where 21 days is coming from the time buffer and the rest 42 days is the ASRLT of this part. The time buffer is divided into green, yellow and red zones which each are one third of the time buffer and hence the length of each zone is 7 days. The last zone is dark red and it is after the order due date which means that part is late and it is causing delay for the parent level item or for the promised delivery date to customer. Lead time alert is providing information for planners on time visibility on the situation with these LTM items by indicating on which zone the item is currently. In the planning window there is needed indication next to alert which tells whether there has been made corrective action for part or if the part needs some actions to be taken. The action can be that part has been received or that planner has sent inquiry for source of supply if the parts promised due date will be reached. (Ptak & Smith, 2011, pp. 474-476).

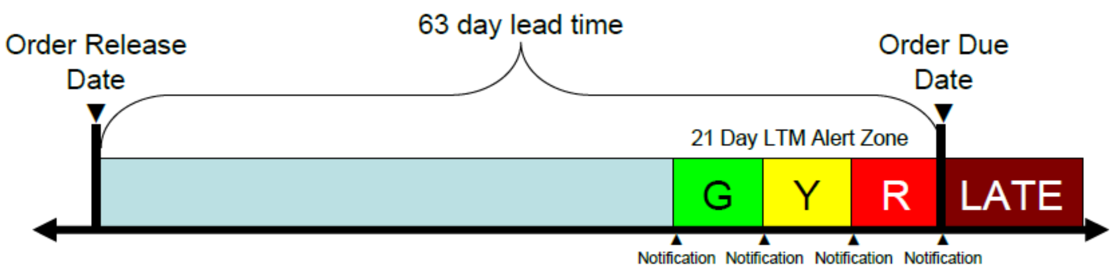


Figure 19: Lead time alert (Ptak & Smith, 2011, p. 474)

In theory there is one interesting point related to LTM parts and lead time alerts that authors (Ptak & Smith) discuss about purchase part so that order due date would be equal to promised delivery date of LTM part which is not perhaps the way how buffering with time is usually used. Often the buffering with time is performed so that ASRLT is used as the supplier lead time when the promised delivery date is the order due date less the time buffer when planners can prevent the system from delays in the supplier lead time by inserting the time buffer between order due date and requested due date in the purchase part. If the lead time alert would be inserted on this type of time buffer then planners could monitor if there will be delays and how closed to actual order due date those delays will postpone the promised date with purchase part. For sub-assemblies on the critical path such monitoring proposed by authors is easier to understand since then the system would not increase the cumulative lead time of the longest path but the lead time would be set minimum. Then these lead time alerts could be used for ensuring that no late deliveries will occur which would create delays on the whole path and hence for the whole system. By using the proposed way of setting the requested and promised date equal to due date the purchasing lead time of LTM parts is extended so that the change of coping with variability is given for the suppliers when those are not requested to operate with shortest possible lead time, which would be equal to their ASRLT, but for the suppliers is given the time buffer of minimum one third from the ASRLT by using the whole buffered lead time as the purchasing lead time.

2.3 Supply chain collaboration

The primary objective of DDMRP system is to improve the ROI through enhancing the flow of operations which will enable company to sell more with less tied up capital. As explained with the first component of DDMRP theory the existing model for DDMRP implementation focuses only on single company when also the benefits of implementation are limited on single company. If the applying company has great extent of vertical integration then also the flow improvement within its supply chain poses large benefits through better synchronization of the whole supply chain. If the applying company has limited vertical integration in its supply chain then also the benefits of flow improvement would be limited on synchronizing only the stages which company operates.

Since the case company in this study is characterized to have limited vertical integration in its production system then also benefits of DDMRP implementation would be limited if it would be applied only on manufacturing stages operated by the case company. This chapter is dedicated on supply chain collaboration theory which could provide theoretical framework for analyzing how the case company could extend its DDMRP system implementation in the upstream of its supply chain through better supplier collaboration which should enable higher benefits due to better supply chain synchronization. The chapter is structured into three parts where first part explains the background of supply chain collaboration, second part describes two theoretical frameworks for implementing the supply chain collaboration and third part is used for elaborating the expected benefits of supply chain collaboration with DDMRP system.

2.3.1 Background

The supply chain collaboration has been widely promoted by consultants and academia during the last 20 years while the collaboration concepts of *vendor managed inventory* (VMI), *collaborative planning, forecasting and replenishment* (CPFR) and *continuous replenishment* (CR) has not received the expected mainstream application despite the concepts are rather simple and individual success stories has been reported from various industries (Holweg, et al., 2005). Reason for this is that the collaboration concepts are not well understood nor properly defined which has created a situation where each and every company understand the meaning of supply chain collaboration differently (Holweg, et al., 2005). To overcome the lack of simple framework which would explain different forms of collaboration Holweg et al (2005) divided the collaboration into forecasting and inventory replenishment dimensions and created categorization model shown in Figure 20 below. In the figure type 0 represents situation without collaboration, in type 1 the buying company shares demand forecast for suppliers, type 2 is the vendor managed inventory (VMI) situation and in type 3 the buyer and supplier has collaborative planning, forecasting and replenishment (CPFR) method in use. This study investigates how case company could create *collaborative, planning, forecasting and replenishment* (CPFR) system where the the DDMRP planning and control logic would be used for controlling the material and information flow between supply chain partners which would create type 3 collaboration – *synchronized supply* – for the case company.

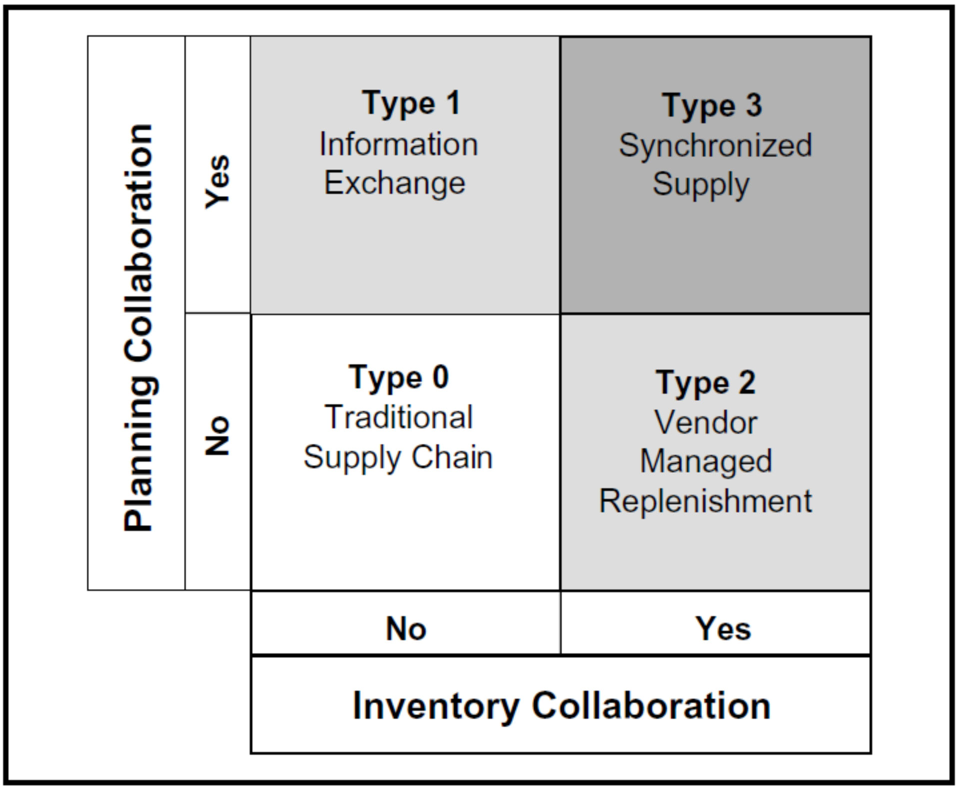


Figure 20: Basic Supply Chain Configurations for Collaboration (Holweg, et al., 2005)

According to Lee and Billington (1992) the successful supply chain management is dependent on the trust and commitment between trading companies who build the products and create the supply chain. Trust is seen as a willingness to avoid opportunistic behaviour by trusting that supply chain partner will keep their promises and work in a consistent manner. Commitment is seen as the willing to put effort on sustaining the relationship with trusted supply chain partners by dedicating resources on sustaining and achieving the common goals in the supply chain. The trust and commitment is not achieved in one night, but there is certain transition process from low degree to higher degree of trust and commitment. In Figure 21 is shown key transition process how important suppliers can become collaborative partners where each step requires different degrees of trust and commitment. The lowest degree is defined as the open market negotiations, second lowest as the co-operation with trading partners which is followed by co-ordination relationship and eventually in the highest degree the relationship can be defined as the collaboration where both trust and commitment are crucial elements for achieving and sustaining this stage. (Speckman, et al., 1998). In addition to trust and commitment Spekman, Kamauf and Myhr (1998) highlighted that collaboration in the supply chain requires information technology which is seen as an enabler and as the key to the development of an integrated supply chain. Where authors also point out that *"supply chain management demands that one look at the complete set of linkages that tie suppliers and customers throughout the value chain*" which is also the motivation for this study to investigate whether the case company could use DDMRP system for on creating this tie from the customers to the suppliers and hence throughout the entire value chain.

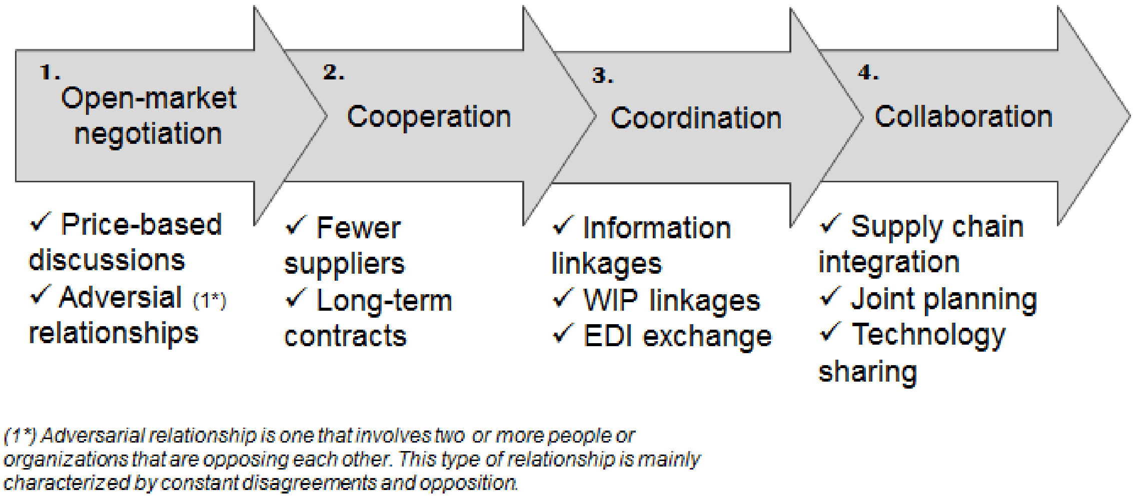


Figure 21: The key transition from open-market negotiations to collaboration (Speckman, et al., 1998)

Andrew Cox (2004) uses *"power regimes"* as the main explaining factor when choosing which level of collaboration is appropriate with whom in the supply chain. As explained earlier (Holweg, et al., 2005) the collaboration in the supply chains has not received as much publicity as what was expected since mid-1990s what Cox (2004) explains with the lack of *"appropriateness"* when buyers have been choosing the partners for whom put commitment to create trust needed for collaboration. Cox (2004) explains that power regime, or more commonly purchasing power of buyer, between seller and buyer should be used as the main factor when making the decision where organisations should put their efforts on creating the supply chain integration and related supply chain collaboration. Author claims that buyers are *"involved in a complex and only partially visible game with suppliers who have their own goals and motives"* (Cox, 2004) which is the reason why buyers needs to consider the power regimes when creating their decisions from the range of alternative sourcing choices which are available for buyers. Figure 22 below shows the four sourcing options of supplier selection, supplier development, supply chain sourcing and supply chain management where each of the approaches requires different levels trust and commitment from trading partners. The *"appropriateness"* means that buyer is capable to identify the approach bring highest benefit and how to implement it effectively which mean that in some situations supply chain management – in this context mean managing and developing multiple tiers of upstream supply chain – is the right approach to be chosen while in other relationship the supplier selection is the most appropriate approach. (Cox, 2004).

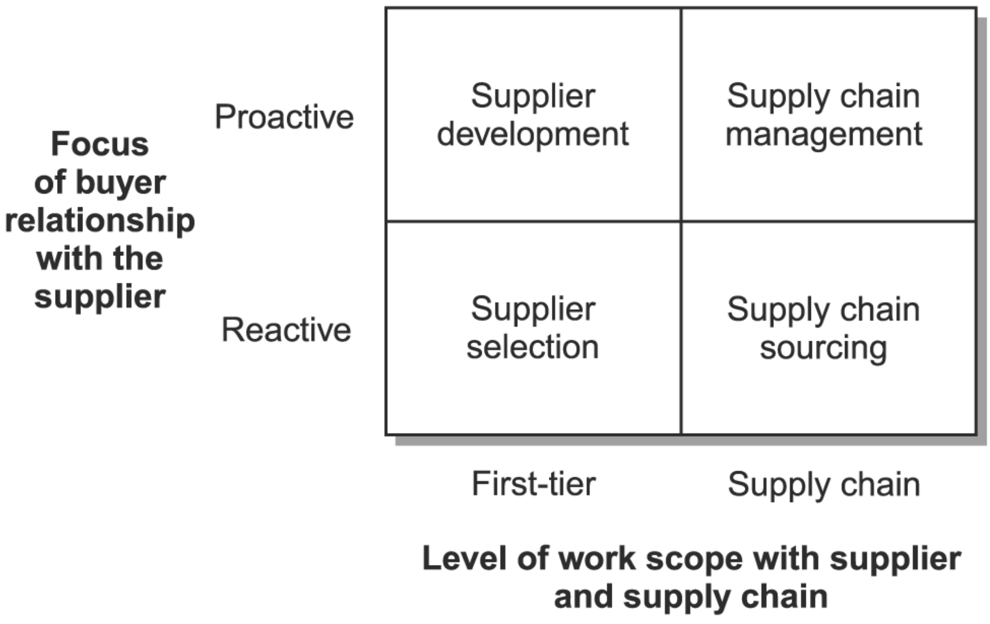


Figure 22: Sourcing options for buyers (Cox, 2004)

Knowing how to implement and choose from the four basic sourcing approaches is not enough for creating *"appropriateness"* in sourcing but buyer need to also understand *"the four basic relationship management choices available for managing suppliers"* (Cox, 2004). When selecting the appropriate sourcing approach the buyer must consider and understand three factors: first the meaning of alternative sourcing approaches, second the power and leverage possibilities in the relationship and third the alternative relationship management styles which can be used when implementing selected sourcing approach in the existing power regimes. The four different power regimes are explained in details on Figure 23 where the research by Cox (2004) shows that proactive sourcing options – *supply chain management* and *supplier development* – are effective only in buyer dominance (>) and in interdependence (=) power regimes where the effectiveness of supply chain management is dependent on the power regimes between tier 1 and tier 2 suppliers.

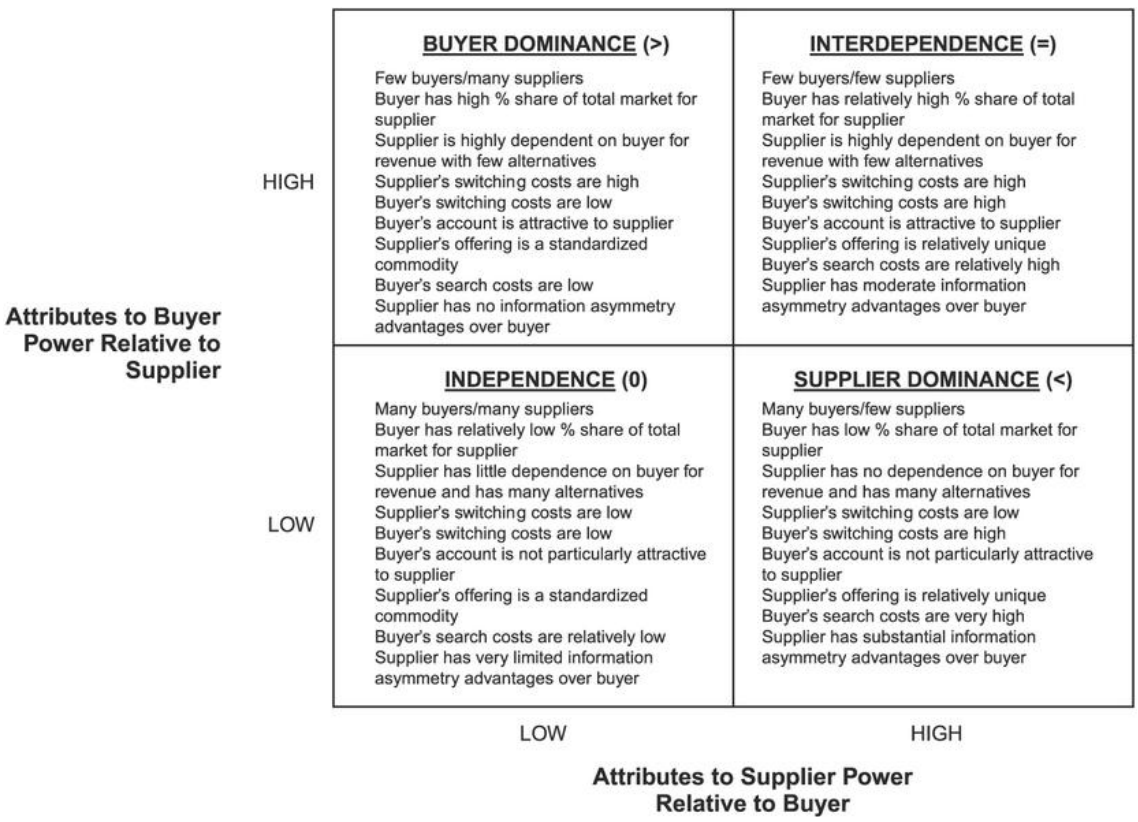


Figure 23: The power regimes (Cox, 2004)

The four different relationship management styles for buyers and suppliers are dependent on two fundamental aspects of the relationship: the value appropriation and the way of working. The value appropriation is the commercial intention of trading partners and it is divided into two dimensions of adversarial and non-adversarial value capturing mechanisms. In the adversarial relationship *"the buyer or supplier is primarily interested in maximising their share of value from the relationship at the expense of the other side"* while in the non-adversarial relationship *"the intention of the buyer or supplier is to provide open and transparent commercial information about profit margins and the costs of operations, such that any improvements can be shared relatively equally"* (Cox, 2004). The way of working describes the operational actions what buyer and supplier makes on maintaining their relationship and it is characterised either as an arms-length or as a collaborative. In the arm's-length way of working partners make only minimal investments in their relationships in a short-term contractual basis where the buyer provides only basic specification, volume and scheduling information to the supplier, as for the supplier provides only a limited specification, scheduling and pricing information to the buyer. In the collaborative way of working partners make extensive investments in their relationship in a long-term basis where in addition to basic specification, scheduling, pricing and volume information sharing the buyer and supplier usually make specific modifications in their operational processes, share detailed longer term information about new product introductions plans and create also technological linkages in those. The purpose of collaborative relationship is usually to *"create a product or service offering at a cost and/or functionality that is not currently available in the market, and could not be created by more arm's-length ways of working"*. (Cox, 2004).

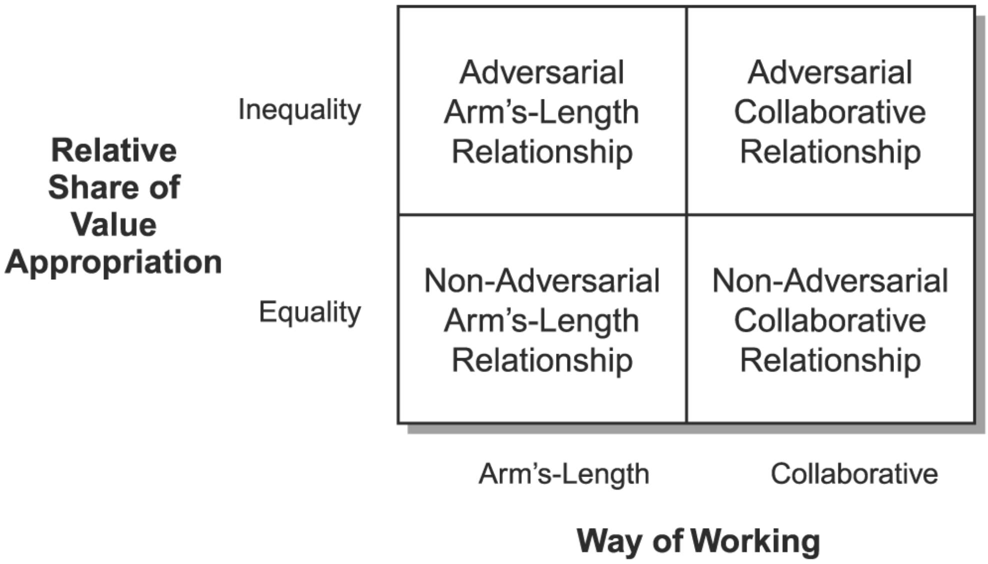


Figure 24: Relationship management styles (Cox, 2004)

According to study made by Cox (2004) there are three main reasons why buyers and suppliers don't achieve their targeted goals in supply chain relationships. First is the lack of internal capability and resources to execute the desired sourcing option, second is the existing external power regimes where partners needs to operate and third is the lack of realising the appropriate relationship management style in the given external power circumstances and internal resource capabilities. The research by Cox (2004) shows that the first and second reasons are difficult overcome while the third reason is possible to overcome by aligning the selected sourcing option, relationship management style and given power circumstances by using the models shown in Figure 26 below. In the Figure 25 below is described more in detail what the alignment would mean in different power regimes and with different way of working styles. Figure 26 takes the sourcing options into consideration and gives proposals when certain sourcing option is feasible to use and gives proposals for appropriate relationship management styles in different power regimes.

THE WAY OF WORKING	BUYER DOMINANT ARM'S LENGTH RELATIONSHIP	BUYER-SUPPLIER RECIPROCAL ARM'S LENGTH RELATIONSHIP	SUPPLIER DOMINANT ARM'S LENGTH RELATIONSHIP
ARM'S LENGTH	• Short-term operational relationship, with limited close working between buyer and supplier • Buyer adversarially appropriates most of the commercial value created and sets price and quality trade-offs • Supplier is non-adversarial commercially and a willing supplicant, accepting work rather than high margins/profitability from the relationship • ***Buyer Dominance power situation (>)***	• Short-term operational relationship, with limited close working between buyer and supplier • Buyer accepts current market price and quality trade-offs • Supplier accepts normal (low) market returns • Both buyer and supplier operate adversarially commercially whenever possible, but normally have few leverage opportunities • ***Independence power situation (o)***	• Short-term operational relationship, with limited close working between buyer and supplier • Supplier adversarially appropriates most of the commercial value created and sets price and quality trade-offs • Buyer is a non-adversarial commercially and a willing supplicant, paying whatever is required to receive given quality standards • ***Supplier Dominance power situation (<)***
	BUYER DOMINANT COLLABORATIVE RELATIONSHIP	**BUYER-SUPPLIER RECIPROCAL COLLABORATIVE RELATIONSHIP**	**SUPPLIER DOMINANT COLLABORATIVE RELATIONSHIP**
COLLABORATIVE	• Long-term operational relationship, with extensive and close working between buyer and supplier • Buyer adversarially appropriates most of the commercial value created and sets price and quality trade-offs • Supplier is a non-adversarial supplicant commercially, and accepts work rather than high margins/profitability from the relationship • ***Buyer Dominance power situation (>)***	• Long-term operational relationship, with extensive and close working between buyer and supplier • Buyer and supplier share relatively equally the commercial value created • Buyer and supplier agree price and quality trade-offs, with supplier making more than normal returns • Both buyer and supplier operate non-adversarially commercially • ***Interdependence power situation (=)***	• Long-term operational relationship, with extensive and close working between buyer and supplier • Supplier adversarially appropriates most of the commercial value created and sets price and quality trade-offs • Buyer is a non-adversarial supplicant and commercially, and pays whatever is required to receive given quality standards • ***Supplier Dominance power situation (<)***
WHO APPROPRIATES VALUE FROM THE RELATIONSHIP?	BUYER DOMINANCE	BUYER-SUPPLIER RECIPROCITY	SUPPLIER DOMINANCE

Figure 25: Value appropriation, power and relationship management styles (Cox, 2004)

SOURCING APPROACH	POWER AND LEVERAGE CIRCUMSTANCE	APPROPRIATE RELATIONSHIP MANAGEMENT STYLES
SUPPLIER SELECTION	BUYER DOMINANCE (>)	Buyer Adversarial Arm's-Length/Supplier Non-Adversarial Arm's-Length
	INDEPENDENCE (0)	Buyer and Supplier Adversarial Arm's-Length
	INTERDEPENDENCE (=)	Buyer and Supplier Non-Adversarial Arm's-Length
	SUPPLIER DOMINANCE (<)	Buyer Non-Adversarial Arm's-Length/Supplier Adversarial Arm's-Length
SUPPLY CHAIN SOURCING	BUYER DOMINANCE (>)	Buyer Adversarial Arm's-Length/Supplier Non-Adversarial Arm's-Length
	INDEPENDENCE (0)	Buyer and Supplier Adversarial Arm's-Length
	INTERDEPENDENCE (=)	Buyer and Supplier Non-Adversarial Arm's-Length
	SUPPLIER DOMINANCE (<)	Buyer Non-Adversarial Arm's-Length/Supplier Adversarial Arm's-Length
SUPPLIER DEVELOPMENT	BUYER DOMINANCE (>)	Buyer Adversarial Collaboration/Supplier Non-Adversarial Collaboration
	INDEPENDENCE (0)	Not Applicable
	INTERDEPENDENCE (=)	Buyer and Supplier Non-Adversarial Collaboration
	SUPPLIER DOMINANCE (<)	Buyer Non-Adversarial Collaboration/Supplier Adversarial Collaboration
SUPPLY CHAIN MANAGEMENT	BUYER DOMINANCE (>)	Buyer Adversarial Collaboration/Supplier Non-Adversarial Collaboration
	INDEPENDENCE (0)	Not Applicable
	INTERDEPENDENCE (=)	Buyer and Supplier Non-Adversarial Collaboration
	SUPPLIER DOMINANCE (<)	Buyer Non-Adversarial Collaboration/Supplier Adversarial Collaboration

Figure 26: Appropriateness in sourcing options, power regimes and relationship management styles (Cox, 2004)

2.3.2 CPFR implementation

In conventional supply chains both the supplier and buyer need to hold safety stock as a way to buffer against variability and uncertainty in demand, supply and operations. The need for safety stock is much more when there is lack of proper demand visibility and no information sharing between trading partners. Martin Christopher (2011, p. 94) uses phrase *"substituting information for inventory"* when describing the benefits of VMI and CPFR programs where the information sharing enables both sides in the supply chain to reduce required safety stock in the supply chain. In the CPFR system the VMI concept is taken further where both parties create jointly agreed decision how information is shared in the chain and how the replenishment orders are generated and delivered in the chain. In the conventional CPFR the information sharing is done through jointly generated forecast which is agreed and signed by parties, supplier and buyer. In figure 27 below is illustrated a nine step model for the CPFR process on how this joint agreement can be made according to Voluntary Inter-Industry Commerce Standards (VICS) organization to support efficient consumer response (ECR) programs. (Christopher, 2011, pp. 94-97).

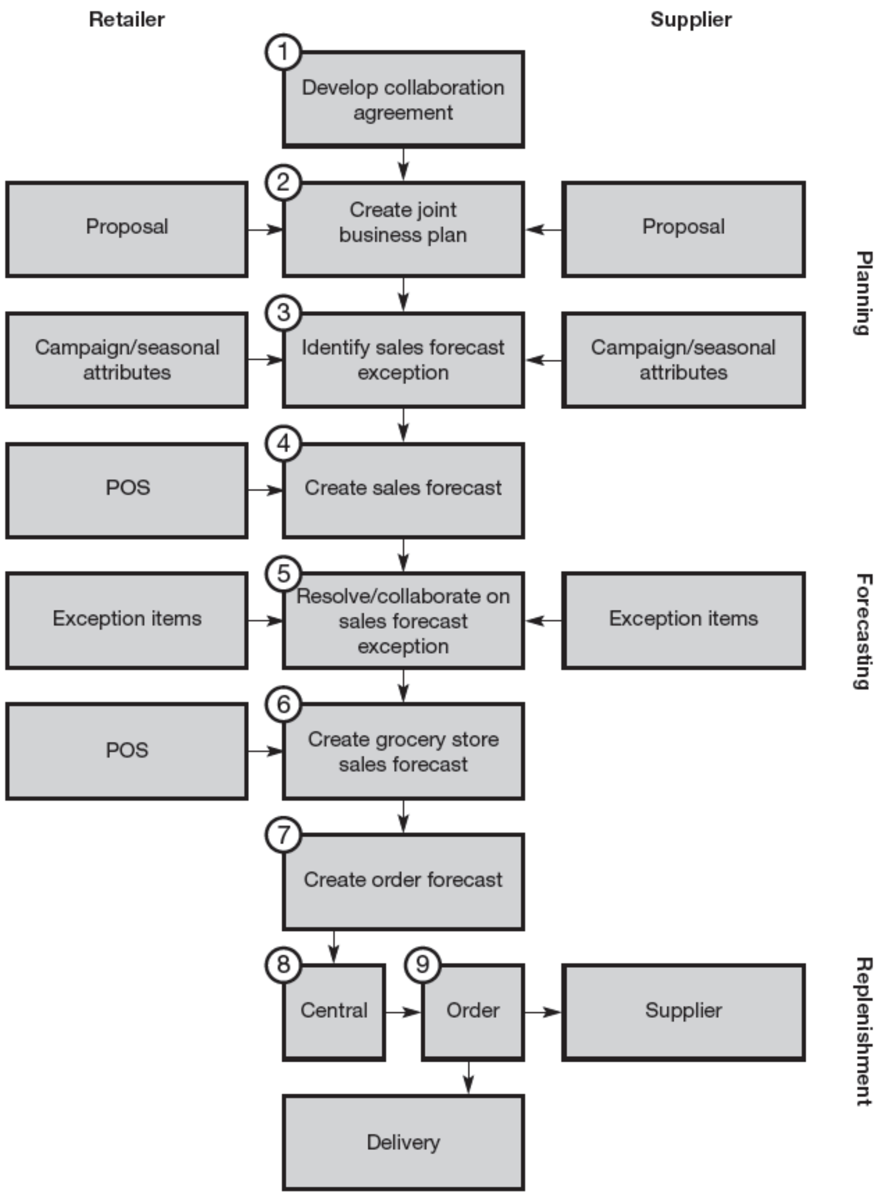


Figure 27: VICS-ECR nine-step CPFR model (Christopher, 2011, p. 95)

Majority of CPFR literature deals with supply chain management in the consumer goods industry where the supply chains are often managed with make-to-stock strategy where the dynamics are slightly different than in the configure-to-order strategy which is used in the case environment of this study. Example the Figure 27 above is developed to support efficient consumer response (ECR) programs and also the study by Holweg et (2005) described earlier focused mainly with consumer goods and related retailer supply chains. The process described in Figure 27 is clearly defined for MRP managed system where the creation of demand forecast for the MRP planning horizon is necessary for getting the system running and generating supply orders. In a study made about the UK naval shipbuilding industry (Sanderson & Cox, 2008) it was showed that the demand forecasting error is much smaller in consumer goods environment than in project environment and hence the reliance on demand forecasting in the replenishment generation is not the advised solution for project environment. This study gives motivation also for this study to investigate how the case company could use the in the CPFR concept the DDMRP system instead of MRP system. This means that the content of the process steps described in Figure 27 should be adjusted to support DDMRP implementation steps. Also the information sharing in DDMRP managed CPFR system would be sharing of: actual demand horizon and order book for the upstream chain, buffer status monitoring from upstream to downstream partners and vice versa together with communication of possible delays and problems which could harm the buffer statuses.

Ronald Ireland (2005) uses *"proven path"* method for the supply chain collaboration implementation which takes a more the change management kind of approach on creating the supply chain collaboration by considering how to change and integrate people, processes, and supportive technology. The proven path method has been used since 1970's for different supply chain system implementations, including MRP II and ERP system implementations, which is the reason why Ireland (2005) uses the method for supply collaboration implementation. The proven path is divided into sixteen steps where first six steps are referred as the "pre-time-zero" steps while the last ten steps are referred as the "post-time-zero" steps. The "time-zero" is when the implementation project is officially launched where the "pre-time-zero" steps are used to create commitment and to provide for the company management necessary information for evaluation if the implementation is seen as beneficial or not. The necessary information for this evaluation is to clarify what is the purpose and scope of the project, how much of resources in people, time and money is needed for implementation, what is the expected benefit of implementing the change and how the project targets and success will be measured. The proceeding ten "post-time-zero" steps are the actual implementation steps where the process is defined, supportive technology is designed and both of these are taken in use by the supportive education throughout the implementation. The complete proven path method for supply chain collaboration implementation project is shown in figure 28 below where the complete list of steps before and after time-zero are listed. For more complete explanation about each step the reader is suggested to take a look on chapter 15 from Ireland (2005). (Ireland, 2005).

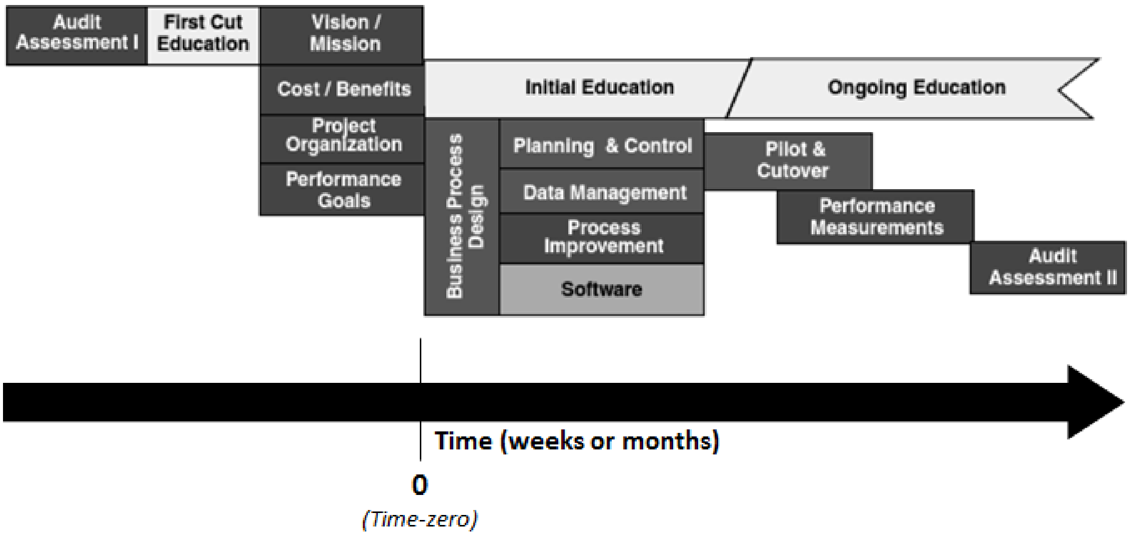


Figure 28: Proven path method for supply chain collaboration project (Ireland, 2005)

2.3.3 Expected benefits

According to Holweg et al (2005) the synchronized supply chain would lead to higher responsiveness and lower inventory costs which both are critical elements when evaluating the benefit of supply chain collaboration project with DDMRP system. USA based company LeTourneau Inc. is one of the early adopters of DDMRP system where the results show how the company was capable to achieve this with the DDMRP system implementation. The company had challenges in early 2000 with its operations of their three similar manufacturing plants located in Houston, in Longview and in Vicksburg where the company had been capable to make only minor total revenue growth from 200 M€ in 2000 to 250 M€ in 2004 while creating only 4% return on average capital employed (RACE) in 2004 when the company invited Constraints Management Group, characters behind the DDMRP theory, for a strategy session where to identify ways to improve company profitability by to overcome their material synchronization challenges on poor on-time delivery performance. The Houston plant decided to continue with conventional MRP system and the Longview and Vicksburg plants decided to take the necessary steps for DDMRP implementation in their manufacturing operations. Figures below show how the total revenues (TR) and inventories (Inv) developed in Houston and Longview plants from 2004 to 2008. The Longview plant was capable to recover from slow market period and increase its total revenue (TR) from 150 M€ to 610 M€ while keeping the inventories (Inv) on reasonable level where the Houston plant was also capable to increase total revenue from 30 M€ to 350 M€ but with a inventories raising hand in hand with revenues. Figures below illustrate how the Longview plant was capable to create synchronized supply chain with an improved market responsiveness, which enabled more sales, and at the same time decrease the relative inventory cost when compared to Houston plant. What is most important here is that the company LeTournau as a whole was capable to improve its return on average capital employed (RACE) from 4% in 2004 to 22% in 2008 by taking the advantage of market growth, total revenue from 250 M€ to 1,190 M€, while at the same time being capable to maintain inventories on moderate level and leverage efficiently the available capacity which resulted in more return with less capital employed. (Constraints Management Group, 2008; Ptak & Smith, 2011, pp. 483-484).

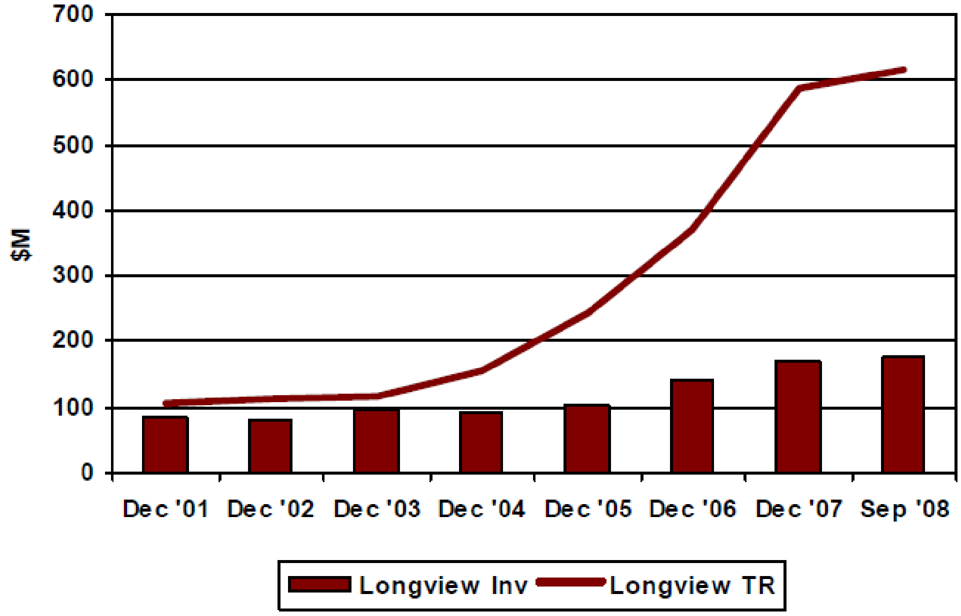


Figure 29: Longview plant with DDMRP system (Constraints Management Group, 2008)

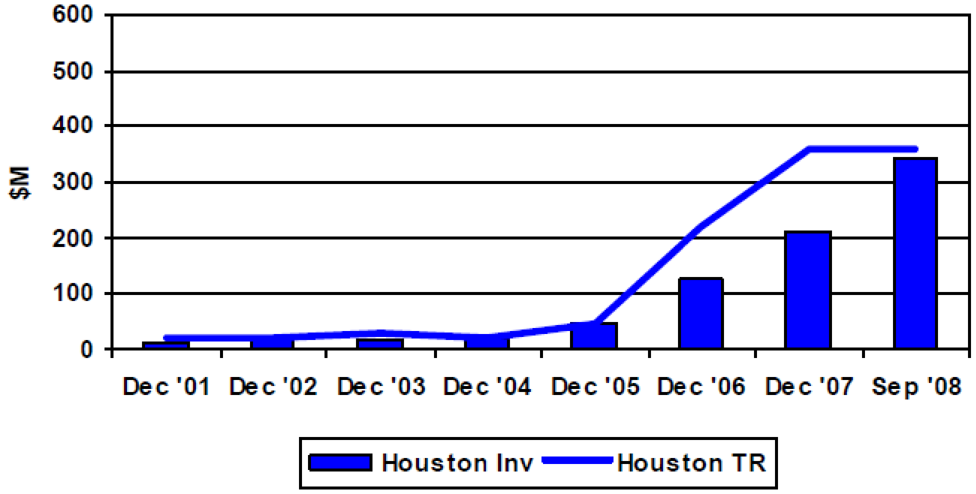


Figure 30: Houston plant with MRP system (Constraints Management Group, 2008)

In order to understand what are the elements behind the return on investment (ROI) formula, or the RACE formula as in the LeTourneau case, the benefit of improved material synchronization needs to be opened a bit further. In the Figure 31 by Martin Christopher (2011, p. 59) is shown the high level components of ROI formula where the return is simplified as the sales revenue minus the costs required for creating the products company is selling. Investment is shown as the capital employed which contains four major components: cash, net receivables, inventory and fixed assets. Next to each component is shown the ways which Martin Christopher (2011) consider as the ways how logistics can impact on ROI formula. In the figure the ways where DDMRP has direct impact through FLOW improvement are rounded with red circles where it can be seen that system can impact on ROI much more effectively than pure cost reduction activities which according to Smith & Smith (2014, p. 103) can destroy ROI when focused on unit cost reduction and local efficiency improvements.

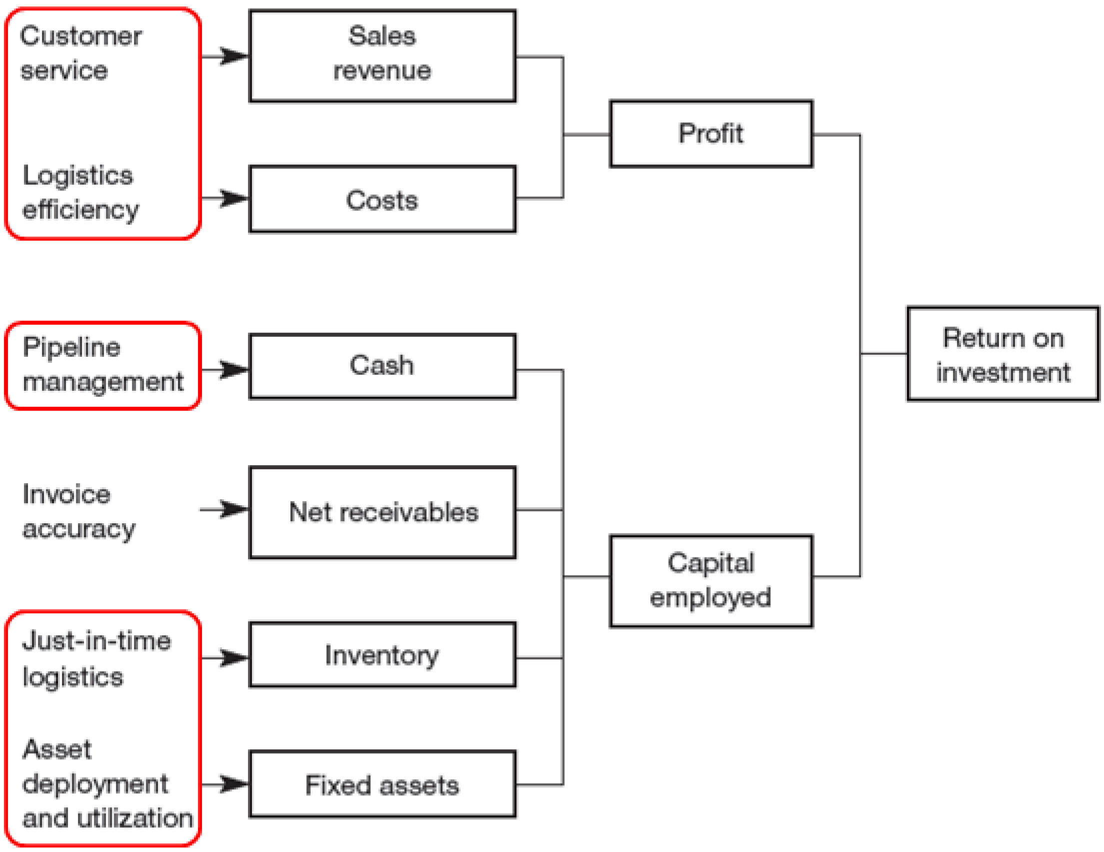


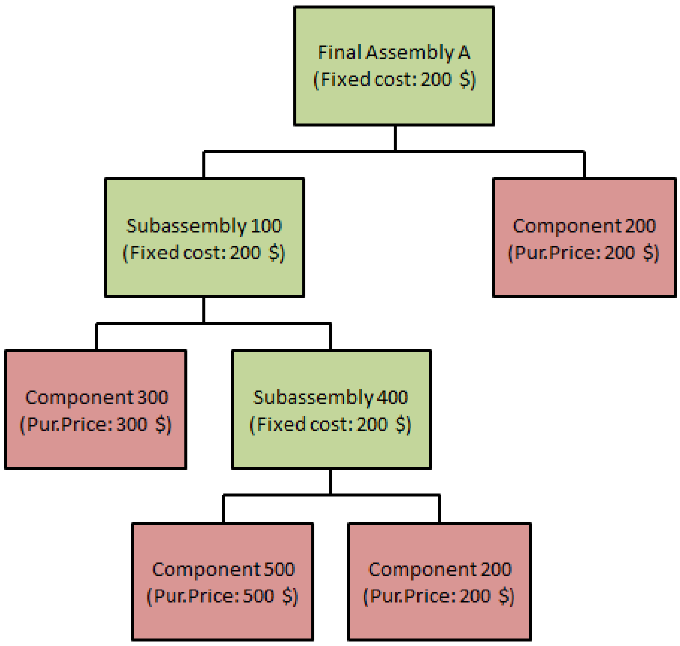
Figure 31: Logistics impact on ROI (Christopher, 2011, p. 59)

The reason for extending the DDMRP system in the value chain upstream in the supplier manufacturing operations is simple because otherwise the supply chain would not generate the full benefit achievable from the synchronization. The reason for extending the system becomes more relevant in companies which have outsourced majority of the actual manufacturing operations to its own supply chain, which was not the case with LeTourneau, when the share of direct material cost can have substantial share from the total cost indicated in ROI formula above. The direct material cost itself is the outcome of the price what company is paying for its suppliers from the materials which are used directly in the products what company produces and sells. If the company improves the flow in its own manufacturing operations it doesn't have impact on the direct material cost per sold unit but it enables company to lower its fixed costs per sold unit by enabling more products to be produced with the same resources (Smith & Smith, 2014, pp. 97-112).

Here it is important to note that the terms *fixed cost* and *variable cost* have different meanings in different accounting approaches. In *"throughput accounting"* the variable cost is assumed to contain only direct material cost while in more conventional *"contribution accounting"* approach the variable cost includes also direct labor and variable overheads which in throughput accounting are considered as a part fixed costs. Main difference between these two approaches is that throughput accounting has a more short term view on the costs while the contribution accounting has more long term view since also the labor and overheads are considered as variable costs. (Drury, 2012, p. 216). For this study the throughput accounting is selected to be used on explaining the benefits of flow improvement.

The purchasing price of direct materials is the outcome of the price negotiated between the buyer and supplier where the supplier can have many alternative pricing methods (van Weele, 2010, pp. 350-352). The *"mark-up pricing"*, also known as *"cost-plus pricing"*, is the most commonly used method because of its simplicity (van Weele, 2010, p. 350) which is supported by a study published in 2006 about 186 UK based companies where 60% of respondents used this much criticized pricing method (Drury, 2012, p. 236). In the *mark-up pricing* the selling price is calculated, example by the supplier of direct material components, by adding defined mark-up on top of the calculated product cost.

Figure 32 below shows the previously used example BOM structure with exemplified cost structure calculation where the mark-up would be defined as 25% from the total product cost when the selling price would become 3.000 $ for the complete part A. If the material and information flow of the manufacturing plant producing this complete part A would be improved it would mean that the output of this plant would increase when it would be capable to produce more the complete parts with the same resources. This output increase would mean lower fixed costs to be allocated per each complete part A. With *mark-up pricing* this would mean lower total cost per single final product A when the selling price could also be reduced in same manner if the mark-up percentage would be kept same.



Cost structure

Variable cost	Component 200	- 200 $
	Component 300	- 300 $
	Component 500	- 500 $
	Component 200	- 200 $
	Variable cost	**1.200 $**
Fixed cost	Final Assembly A	- 400 $
	Subassembly 100	- 200 $
	Subassembly 400	- 200 $
	Overhead allocations	- 400 $
	Fixed cost	**1.200 $**
	Total cost	**2.400 $**
	+ Mark-up (25%)	**+ 600 $**
	Selling price	**3.000 $**

Figure 32: Example BOM with cost structure

If this cost structure would indicate the buying company situation then the internal flow improvement would improve only the internal operations – *green blocks* – when company could improve its profitability since more volumes with +25% mark-up would mean more profit. But if the company would extend the flow improvement into its upstream supply chain then also remaining 50% direct material share from the total cost – *red blocks* – could be reduced due to lower selling price of the parts produced by DDMRP synchronized supplier. Figure 33 below presents results by Martin Christopher (Christopher, 2011, p. 96) what companies have been capable to achieve with CPFR implementation and though the better supplier synchronization in their supply chain.

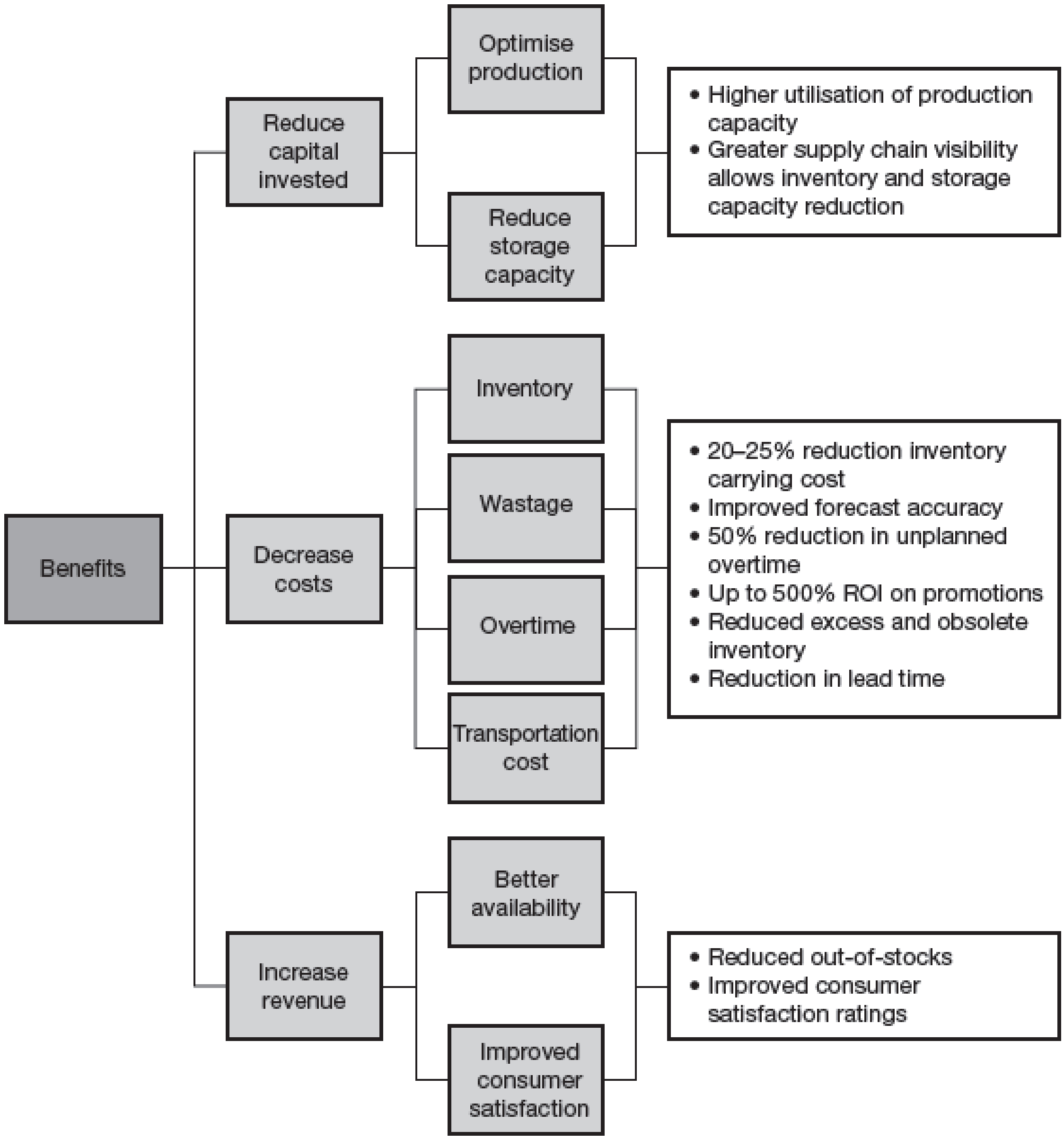


Figure 33: Benefits of CPFR (Christopher, 2011, p. 96)

Challenge with such collaborative project can be the question which party *appropriates the value* (Cox, 2004) from the commercial relationship and hence from the possible efficiency improvement initiatives in supply chain. In *non-adversarial relationship* with open book accounting (OBA) in use the achieved benefits would be easy to link in component pricing but since such OBA practice is still relatively uncommon between trading partners (Kajüter & Kulmala, 2010) this wouldn't provide answer for most of the cases. For collaborative non-adversarial relationships (see Figure 26 in background chapter) the one objective of collaborative DDMRP system implementation could be to open the books and hence ensure that the benefit of such improvement project would be reflected in component pricing. Alternative for open book accounting could be to utilize *"cost modelling"* (van Weele, 2010, p. 356) technique where the buyer makes detailed cost break down proposal for supplier on what the component cost structure could be before and after the implementation project. Based on the proposal the buyer can set a "*should cost"* target for supplier on what the price should be after the improved flow in manufacturing operations gained through the DDMRP system adaptation (van Weele, 2010, p. 356).

In collaborative relationship the *cost modelling* could be used also in conjunction with the open book accounting so that buyer and supplier could jointly set the cost down targets for collaboration project and how those could be translated into selling prices of components. Important for the target setting is to understand the *cost-volume-profit* (Smith & Smith, 2014, pp. 97-112) relationship and hence the *"target return pricing"* (van Weele, 2010, pp. 350-351) method could offer better framework for price calculations than the convention *mark-up pricing* explained earlier. In the *target return pricing* the price is defined based on the profit target by using variable cost, fixed cost and required sales volume information. The first step is to calculate break-even volume and based on this calculate the required extra volume to achieve the profit target. If the required extra volume can be realized then the price is on sufficient level, if not then then either the volumes or price needs to be adjusted. Simplified example of *cost-volume-profit* (Drury, 2012, p. 175; Smith & Smith, 2014, p. 109) and related *target return pricing* is shown in Figure 34 below. In the example is used the cost structure described above by assuming that 1.200 $ fixed cost was calculated for 100 pieces when the break-even point is on 67 pieces and with 100 pieces company generates 60.000 € profit which means 20% profit margin from the net sales. If the company would be capable to produce more with same resources, then the price could be lowered or the profit could be increased.

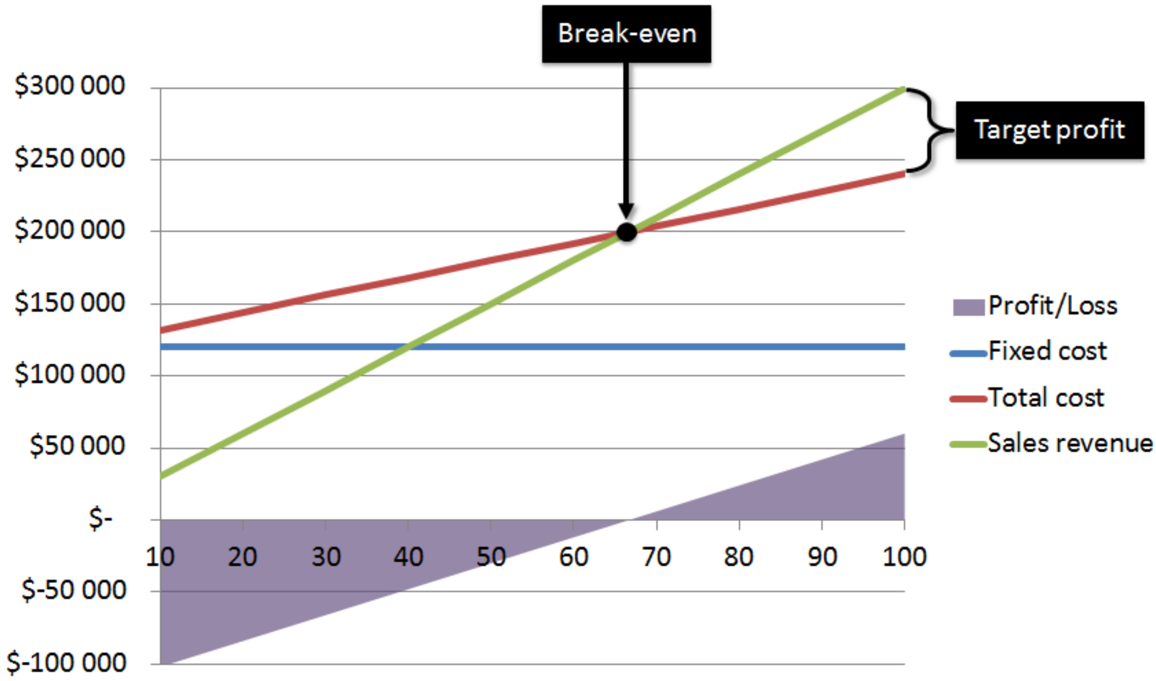


Figure 34: Target profit with example BOM with 100 pieces sales volume

3. RESEARCH METHOD AND DATA COLLECTION

Purpose of this research is to provide answer for two research questions: *how the supply chain synchronization with DDMRP implementation could improve responsiveness and lower inventory cost (**RQ1**)* and *how to implement DDMRP in non-vertically integrated supply chain (**RQ2**).* According to Yin (1994, p. 38) there are four different types from which to choose when designing a case study research. *Embedded multiple-case design* (Yin, 1994, p. 39) research method is selected on this study for examining the answers for both of the research questions above. Reason for selecting the multiple case design is to test the how the DDMRP implementation would differ for different products, production processes and demand characteristics where the theory suggests that these three dimensions affect into the first and two components – *strategic inventory positioning* and *buffer profiles and levels* – of DDMRP implementation (Ptak & Smith, 2011) and related customer order decoupling point (Olhager, 2003; 2010) positioning decision. Multiple case study with a replication logic is favored for a study where is explored multiple cases for single purpose (Yin, 1994, pp. 44-45). In this study the purpose is to investigate how to implement the DDMRP theory in a single case company by conducting three case studies for different kind of supplier relationships and for different purchase parts with different conditions affecting to DDMRP parameters. Yin proposes to select observed cases so that each case *"produces contrasting results but for predictable reasons"* (Yin, 1994, p. 46). In this study the predictable reason is explained in the theory while the contrasting results on inventory positioning and buffer profile are expected for the DDMRP implementation due to different product, process and demand characteristics.

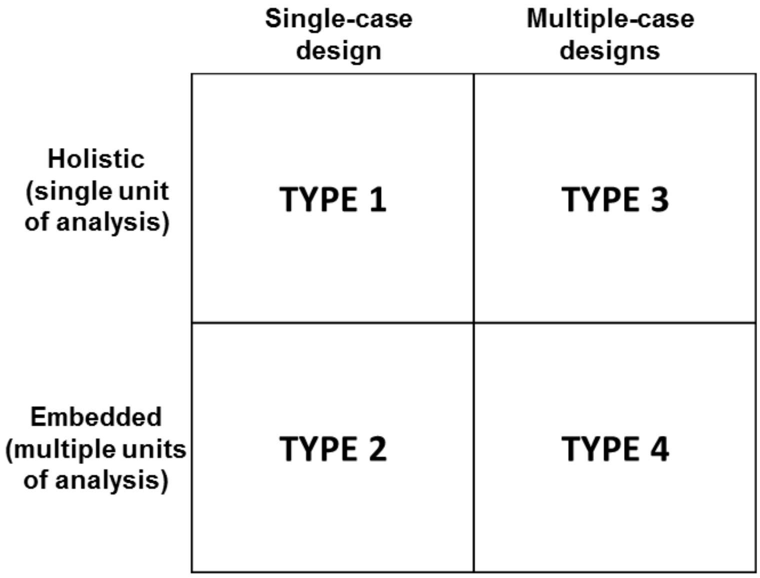


Figure 35: Basic types of designs for case studies (Yin, 1994, p. 39)

Reason for using *embedded* (multiple units of analysis) instead of *holistic* (single unit of analysis) is because the DDMRP implementation is investigated for all different purchase part variants from single product family since the different purchase part variant has different demand characteristics when the prediction is that the calculated buffer levels will be different due to variation in the demand. If there would be only single unit of analysis for each case purchase part type the results wouldn't give comprehensive results for the buffer level calculations which is part of answer on RQ1 when the expected reduced inventory cost is calculated for the whole variant group of single case and purchase part type. Another option would be to conduct multiple case study with a scope in the *"global nature of a program or of an organization"* when the study would be considered as a *holistic,* with single organizational unit of analysis (Yin, 1994, p. 42). With this approach the typical problem with the holistic design *"that the case study may conducted at an abstract level, lacking any clear measures or data"* (Yin, 1994, p. 42) would be realized for this study which would not be according to interests of the studied organization which wanted to have practical study on the DDMRP implementation in their organizational environment. One wish for the study was to get measurable results on the inventory cost reduction with the actual data from the company ERP system. The selected *embedded multiple-case studies* research process is designed according to the case study method example by Yin (1994, p. 49) where was added two steps before the process starts with theory development. The adapted and applied research process is illustrated in Figure 36 below.

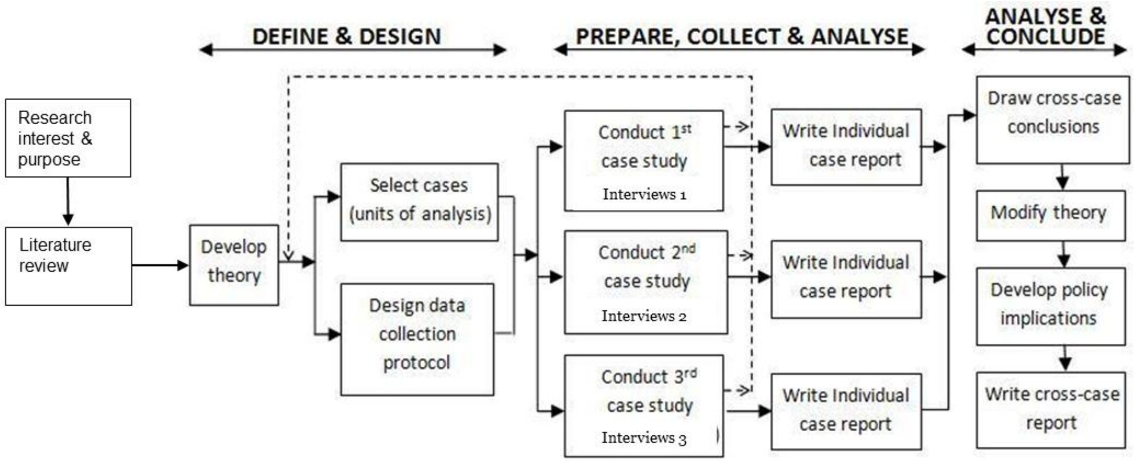


Figure 36: The applied research process in this study

The overall purpose of the data collection in this study is to identify demand, product & production related factors affecting into CODP position and DDMRP components 1-3, also the supplier relationship perspective is covered in the data collection by using the theoretical models by Andrew Cox (2004). Data collection for the research is performed with qualitative interviews for key personnel in the case company who are working with the three case purchase parts. The data collection with the interviews is divided into three different questionnaires where the whole required information is divided into these questionnaires according to competence areas of each interviewed person. The interviewed personnel for each case are: strategic purchaser related to supplier relationship management style, supplier development engineer related to production process of the case parts and operative purchaser for the current material management related questions. For the case 1 the interviews is expanded for the manufacturing experts in the case company production department since the investigated parts are partially manufactured internally while production process related information is collected also from them. The cases 2 and 3 are manufactured externally and hence have lower level of vertical integration than the case 1. In addition to the qualitative data collection the study uses quantitative data collected by the researcher from the company ERP system. The quantitative data is mainly related to the consumption and demand history of the investigated purchase parts for cases 1, 2 and 3. In addition to the demand data the researcher collected bill-of-material (BOM) data for the case 1 from the company ERP system which is needed for the inventory positioning and buffer profiles and levels. For the case 2 the BOM information is collected after the official data collection information since the interviewed person received the BOM data after the interview of this research.

For each three cases the individual case reports are created for the case company with the actual supplier names, and purchase part identification numbers and names. From these three individual case reports is created cross-case conclusions for answering the RQ 2 in format of project proposal on how the implementation could be done in the case company. The conclusion for this proposal is based on the analysis and conclusions created from the three cases investigated in this study. For the RQ1 is presented results only for the case 1 since it is only component for which the inventory reduction cost is possible to calculate with the DDMRP theory on average inventory holding for strategic replenishment buffer. Cases 2 and 3 are designed to be managed with lead time managed buffers and for this strategic buffer type the theory does not provide calculation formula. For the cases 2 and 3 the result for RQ 1 would require company to proceed within the actual implementation when the actual inventory cost reduction could be observed in longitudinal study from the beginning until the end of the implementation project. Also for the case 1 the validity of the results would be improved if the results could be observed in longitudinal study on the actual inventory cost reduction instead of using the calculated cross-sectional results. Also the results for RQ would be more valid if the study could be conducted in a longitudinal experimental study when the researcher could compare the expectations before and after the project and DDMRP is implemented.

The data collection for this study is performed in similar format for each of the three cases with formal interviewing templates to improve the reliability of the data. Because the interviewed data is qualitative by nature the reliability can always be questioned since the answers depend much on the person who provide answers. If the all of same interviewing questions would be asked from all different key stakeholders there probably would be different results for the qualitative questions. In this case the reliability could be even more questionable since the respondents would then give answers on topics which are not directly related into their daily job and competence areas. For this reason the selected data collection method was selected in order to be capable to get as reliable results as possible for this cross-sectional research. Reliability of the quantitative data is relatively high since the data is based on records in ERP system where the main questionable feature can be the days when the consumption is entered into the system. In some cases there can be delays in entering the consumption data, but the delay would not be significant when the analyzed time horizon is relatively long and since the average consumption information is used for buffer level calculation.

4. RESULTS AND DISCUSSION

The results for the research question: "*How to implement DDMRP in non-vertically integrated supply chain?*" is presented in two sub-chapters. The first sub-chapter describes how first three components from the *five components of DDMRP* could be modelled in the case company environment for the selected examples. The detailed modeling is presented only for case purchase part 1 while the cases 2 and 3 are presented only with a summary description and high level illustrative figures in the end of the first sub-chapter. The last two from the *five components of DDMRP* are included in the second sub-chapter where is described how the actual implementation project could be done in the case company and its upstream supply chain. Reason for this is that the components 4 and 5 would require actual implementation of components 1-3 before those can be defined and tested in the case environment. The first three components of DDMRP implementation can be modelled in the environment without actual implementation of the system.

4.1 Pre-study: modelling the environment for example cases

This sub-chapter is a pre-study for the actual DDMRP implementation project where the components 1-3 are modelled for three different case purchase parts to give for the company an understanding what the first three steps – *modelling/re-modelling the environment* – would mean in their environment before the company would enter into the actual DDMRP implementation project. Figure 37 shows the *five components of DDMRP* and the selected components 1-3 included in the scope of this pre-study.

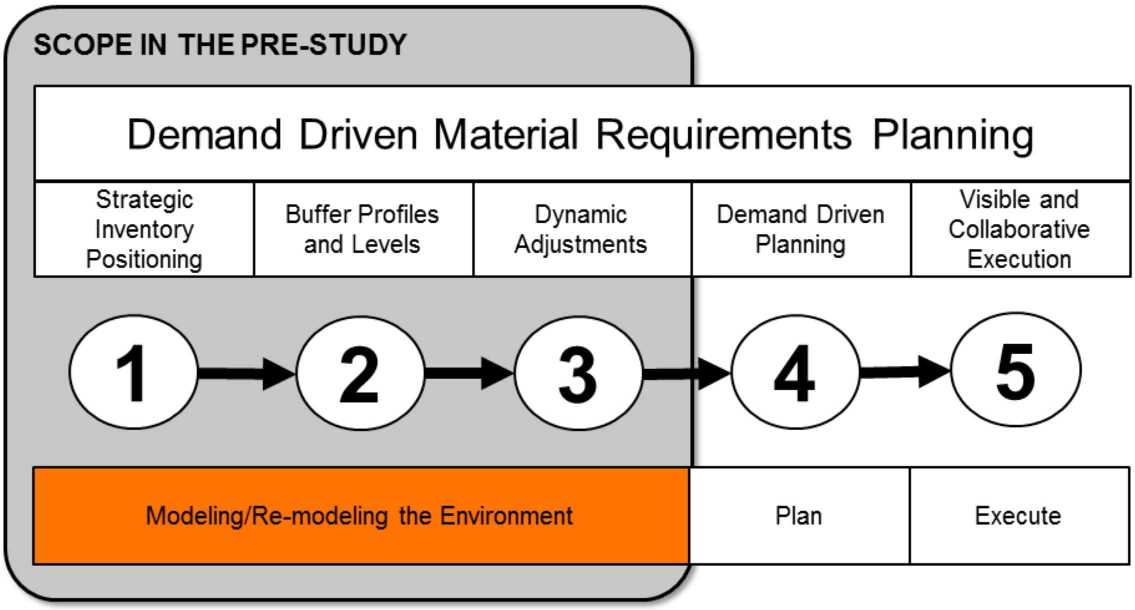


Figure 37: Scope in the pre-study

4.1.1 Strategic inventory positioning of case 1

Component 1: Strategic inventory positioning is answered by using two decision making models. First the high level product delivery strategy and associated CODP position is proposed by using the *model for choosing the right product delivery strategy* by Jan Olhager (2003). Second the more detailed inventory position is proposed by calculating an expected benefit with the *ASRLT* and *Matrix BOM* from the DDMRP theory (Ptak & Smith, 2011, pp. 396-403).

The high level end-to-end supply chain of case component 1 is illustrated in Figure 38 below. Orange boxes and arrows indicate processes and material movements which are controlled by Wärtsilä. The focus of this study is limited to the part of the chain between ***Wärtsilä 4-Stroke*** and ***Casting supplier*** and hence the full end-to-end supply chain is not taken into consideration but is illustrated to give for the reader better overview about the context where the case supply chain belongs to.

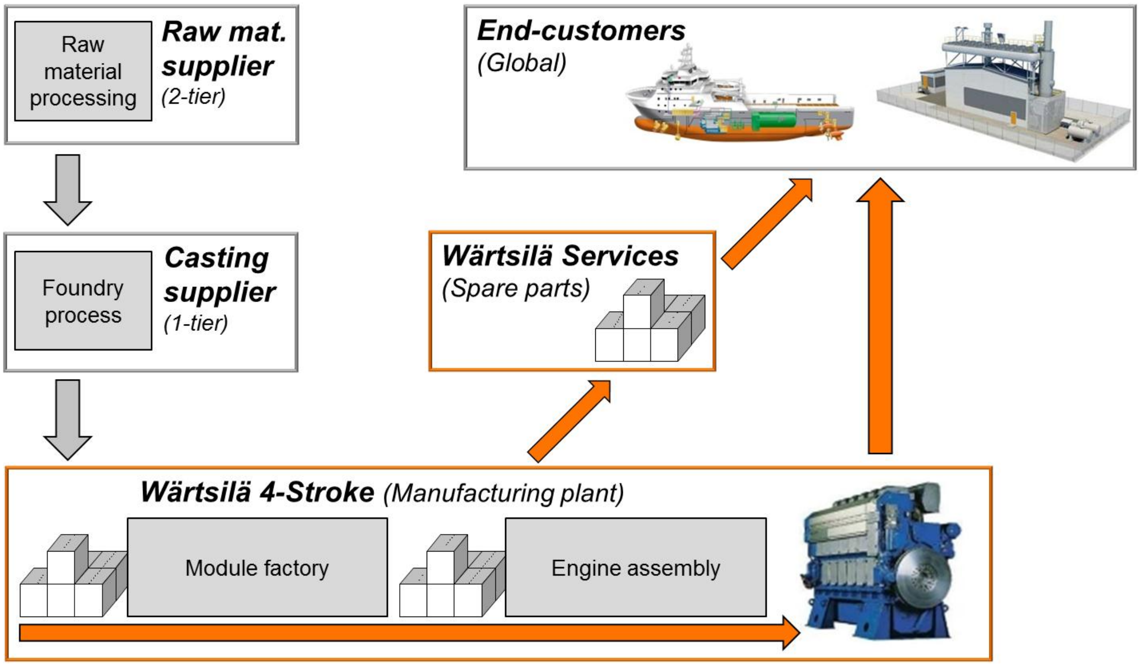


Figure 38: Supply chain of case 1

For the *model for choosing the right product delivery strategy* two critical characteristics of case components are identified: *Relative Demand Volatility* (RDV) and the ratio between *Production lead time* and customer tolerant *Delivery lead time* (P/D ratio) (Olhager, 2003). The case component 1 is a typical example of mass customisation where the product differentiates in the late stage of production process which in this case is located in the late stage of manufacturing process done in the module factory of Wärtsilä 4-Stroke, illustrated in Figure 39 below. In general the demand is much more volatile when moving downstream in the manufacturing process compared to upstream due to effect of inventory risk pooling (Simchi-Levi, et al., 2008, pp. 190-191) and hence the RDV values increase dramatically when the amount of SKUs increase. Also the P/D ratio differs in the case supply chain due to non-vertically integrated production process. Below is presented P/D ratios from the current state for the different parts of the case supply chain:

- **Wärtsilä 4-Stroke**: $P_{Manufacturing\ plant} < D_{End\ customer}$
- **Casting supplier:** $P_{Foundry\ process} > D_{Wärtsilä\ 4-Stroke}$
- **Extended supply chain:** $P_{Foundry\ +\ Manufacturing} > D_{End\ customer}$

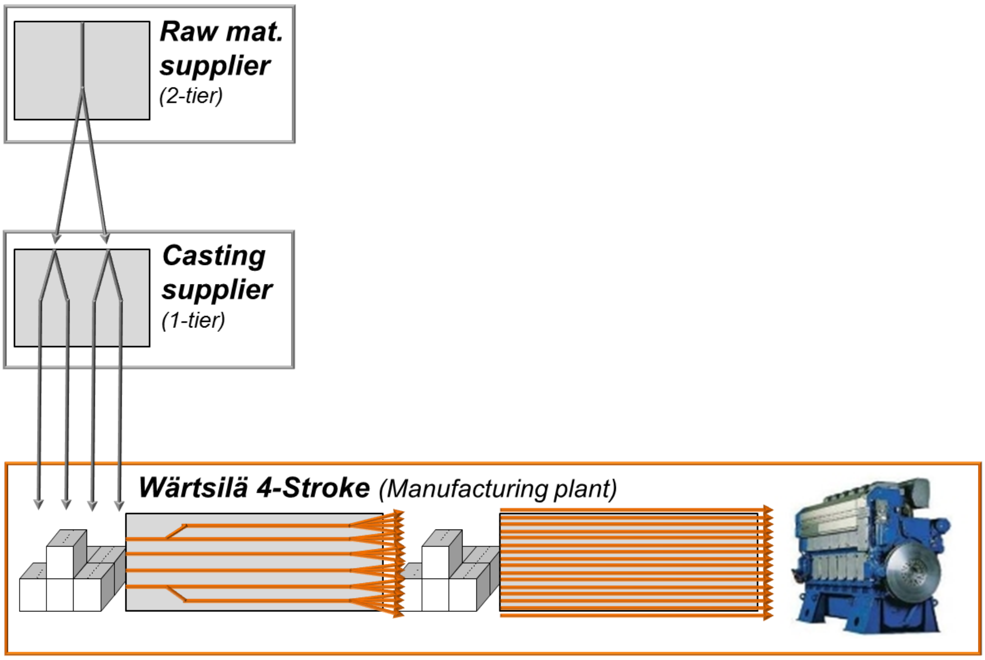


Figure 39: Product differentiation of case 1

In order to identify the optimal product delivery strategies for both of the parties of the chain – Casting supplier and Wärtsilä 4-Stroke – the RDV values and P/D ratios are located in the *model for choosing the right product delivery strategy* (Olhager, 2003) to get an high level overview how the CODP should be positioned in the supply chain. According to the model Wärtsilä 4-Stroke should pursuit for MTO strategy due to high RDV and P/D ratio below 1. Casting supplier should choose the MTS strategy due to low RDV and P/D ratio above 1. For the extended supply chain the ATO strategy would be the most recommended strategy because RDV is high and P/D ratio is above 1. Below in Figure 40 is presented optimal product delivery strategies for the different parts of the supply chain with the case component 1.

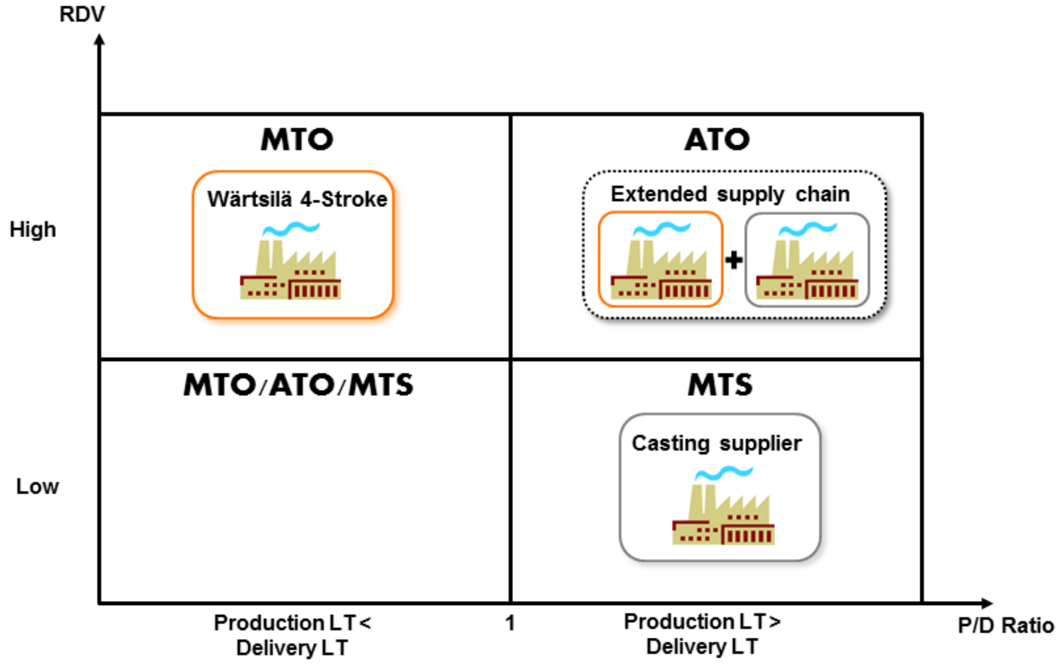


Figure 40: Choosing the right product delivery strategies for case 1

Second step after identifying the desired high level product delivery strategies is to find ways how to put the selected strategies in place within the actual manufacturing operations. The high level strategy does not yet reveal where and how much to place strategic inventories in the case supply chain but it gives direction of the solution where the customer order decoupling point (CODP) should be located between the organisations involved in the extended supply chain. For **casting supplier** MTS strategy the CODP should be located in the finished goods stock when **Wärtsilä 4-Stroke** would order directly from this stock point for the requirements of its operations. For **Wärtsilä 4-Stroke** MTO strategy the CODP of this case component should be located in raw material stock meaning that when the end customer places order the case component would be manufactured from the raw material stock. When looking decoupled ATO strategy of the **extended supply chain** there would exist only one CODP which would be located between different manufacturing phases of **Wärtsilä 4-stroke** and **Casting supplier** when both of the parties would operate according to the same drum beat set by customer orders in the master production schedule of Wärtsilä 4-Stroke.

Below in Figure 41 is presented overview on the BOM structure with ASRLT of complete product where the analysed case component is used. Since all of the purchased components are purchased to stock, and hence are stocked items, the longest leg is defined by the routing where case component – purchase part 301 – is used for machining 201. Other purchase parts used for 1 and 2 level of BOM structure are clustered in same boxes to create simplified overview. Purchase parts used in level 1 are grouped in two boxes where the parts 102-118 hold 50% and parts 119-135 hold only 1% of the total direct material value of the final product A. Sub-assembly 101 hold 49% of the whole value of direct materials of the final assembly A.

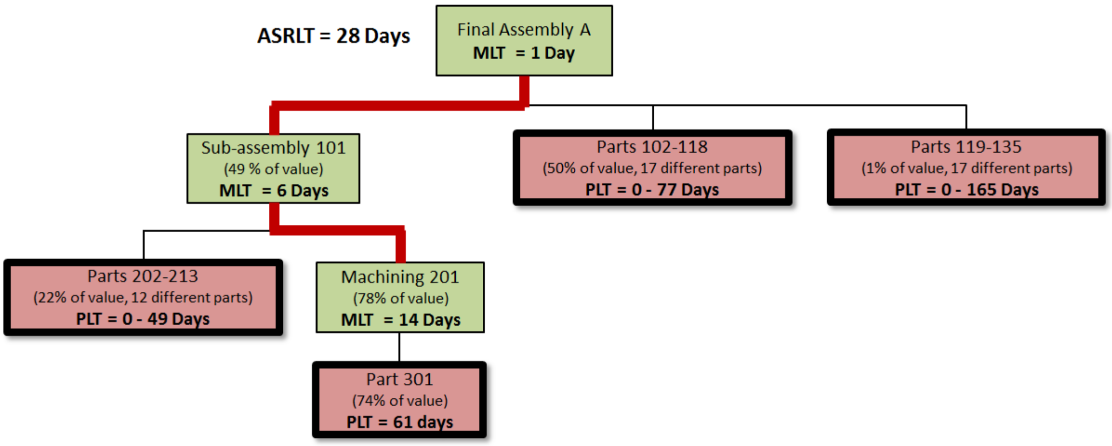


Figure 41: Overview of where case component 1 (Part 301) is used

Since the scope of this study is to evaluate interfirm DDMRP implementation across organisational boundaries, the BOM and ASRLT analysis needs to be continued on supplier manufacturing process and into the lower BOM levels of purchase part 301. In Figure 42 are described the manufacturing process with processing times, BOM structure and ASRLT of Wärtsilä's purchase part 301 to show that the purchase part 301 is a parent level item for its own supply chain and for the product of casting supplier.

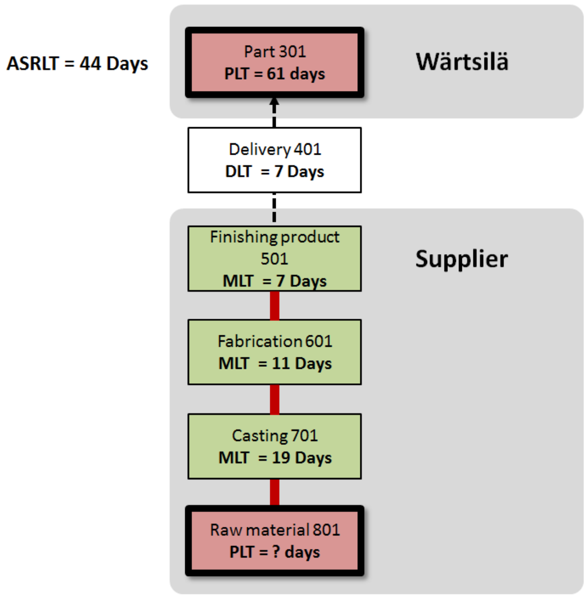


Figure 42: Structure of part 301

The **casting supplier** should pursuit MTS strategy for the purchase part 301 according to Figure 39: *Product differentiation of case 1* and Figure 40: *Choosing the right product delivery strategies for case 1*. When moving decoupling point to downstream, from MTO to MTS strategy, the biggest expected resistance is supplier's reluctance to hold inventory in finished goods because of *upstream forces* of product market constraints and inventory cost consideration (Hoekstra & Romme, 1992; van Donk, 2001). For the current *co-operative* supplier relationship it is important to evaluate how the supplier's shift to MTS strategy with interfirm DDMRP implementation would affect into upstream forces in combination with the possible effects to *downstream forces* of process constraints and delivery service requirements**.** With this approach the system wide impact could be considered and possible sub-optimisation avoided which are essential elements when creating the trust and commitment required for development of the relationship from *co-operation* to *co-ordination* and *collaboration* (Speckman, et al., 1998; Vollmann, et al., 2005, pp. 530-533).

Because the purchase part 301 is already a stocked part, but stocked in Wärtsilä's side, the shorter delivery lead time from supplier to Wärtsilä should reduce inventory levels in downstream side of the chain, meaning inbound storage required to run machining operations. On the other hand supplier is likely already holding some level of cycle and safety stock in their finished goods due to once per month ordering frequency and once per week deliveries to Wärtsilä. To find an optimal inventory solution for the whole chain, and to overcome the expected resistance for holding inventory in finished goods, three questions needs to be answered:

1. How much supplier should increase finished goods inventory if they would move from current MTO strategy to MTS strategy with DDMRP?
2. How much this change would reduce the amount of inventory needed on the downstream side?
3. What would be the impact to system wide total inventory investment?

For the first question this study cannot give complete answer because the actual average finished goods (FG) stock levels in supplier side were unknown for all of the variants during the interviews. Only for variant 4 actual WIP data was available from interfirm improvement project which was conducted together with supplier. This *actual WIP* included the full work in process without separation between intermediate stocks (WIP) and finished goods (FG) stock and hence it gives only a reference amount to illustrate the fact that supplier is already having inventories in the process despite operating with MTO strategy where the quoted delivery lead time is longer than actual cumulative manufacturing lead time. For the variant 4 the production batch size is fixed 96 pcs when the average intermediate WIP level would be 48 pcs and hence the rest 114 pcs from actual full WIP could be FG stock. In order to make slightly more moderate FG assumption the intermediate WIP level is assumed to be full batch size 96 pcs when the rest 66 pcs from full 162 pcs of full WIP would be FG stock.

For all variants 1-4 a rough estimate of the average total finished goods stock is calculated to be 105 pieces, equal to 109.000€ in book value, by using available consumption data of purchased parts in Wärtsilä side and with the given delivery frequency. Average cycle stock level is calculated as 50% of weekly demand calculation and safety stock is assumed to be 50% of cycle stock. Coefficient of variation is given as a reference but is not included in safety stock calculation. When comparing with variant 4 the calculated 27 pcs FG level to actual assumed 66 pcs FG level it can be seen that the calculated FG level is only 40 % from the actual assumed level but because there was no actual FG level available for all variants the calculated value is the best alternative to be used. In the appendix are included details of current FG stock level calculations.

DDMRP buffer calculation method was applied for estimating average FG stock level of 477.000 € required in MTS strategy controlled with DDMRP. This level was compared to current 109.000 € FG stock level, MTO strategy controlled with MRP, to give answer for first question: *"how much supplier should increase inventory in finished goods if they would move from MTO to MTS strategy?"* The total difference in FG stock holding equals 355 pieces worth of 368.000 € inventory investment where the average total FG stock level would increase from 105 pieces to 460 pieces. Details of calculations can be found from appendix. As stated earlier the actual increase in FG inventory is probably less than calculated since the actual current FG level is probably around 60% higher than the calculated 105 pieces with 109.000 € in book value. The investigation of current actual average level is one of the main deliverables to be investigated in the *Initiation* phase of DDMRP implementation project.

The answer for the second question: *"How much this change would reduce the amount of inventory needed on the downstream side"* is given by comparing actual inbound stock level of Wärtsilä 4-Stroke to average on-hand level calculated with DDMRP buffer calculation. The inbound stock reduction would be 943 pieces and 1.013.000 € if the ASRLT and hence supplier delivery lead time would be reduced to two weeks which should be possible with MTS strategy where the first week is reserved for order intake and delivery arrangement and second week for delivery to customer. Inbound stock reduction would be 579 pieces and 640.000 € if the supplier would hold the MTO strategy with current 61 days ASRLT and delivery lead time and only Wärtsilä would implement the DDMRP for the controlling of inbound stock. Hence the difference in inbound stock of Wärtsilä is 365 pieces and 372.000 € when comparing MTS and MTO strategy of supplier.

For the third question: *"what would be the impact to system wide total inventory investment"* the result is calculated by comparing current total inventory to DDMRP implementation with ASRLT 61 days (MTO) and with ASRLT 14 days (MTS). With ASRLT 61 days (MTO) the total system wide inventory reduction would be 579 pieces and 640.000 € and with ASRLT 14 days (MTS) the reduction would be 589 pieces and 645.000 € where the difference between MTS and MTO strategies is only 10 pieces and 5.000€. These results are calculated by using the calculated FG level in supplier side where the assumption is that calculated FG level is only 40 % of the actual FG level. By using the expected actual FG level the difference between DDMRP implementations with ASRLT 14 days (MTS) and ASRLT 61 days (MTO) would be more significant where ASRLT 14 days (MTS) would have 167 pieces and 168.000 € less system wide inventory than ASRLT 61 days (MTO). This finding supports DDMRP implementation illustrated in Figure 43 where supplier inventory positioning and MTS strategy enables ASRLT of 14 days for purchase part 301 of Wärtsilä. When comparing presented supply chain to current situation, by using expected actual FG level, the total system wide inventory reduction would be 746 pieces and 809.000 € which is 47% less tied up capital in than in the current situation.

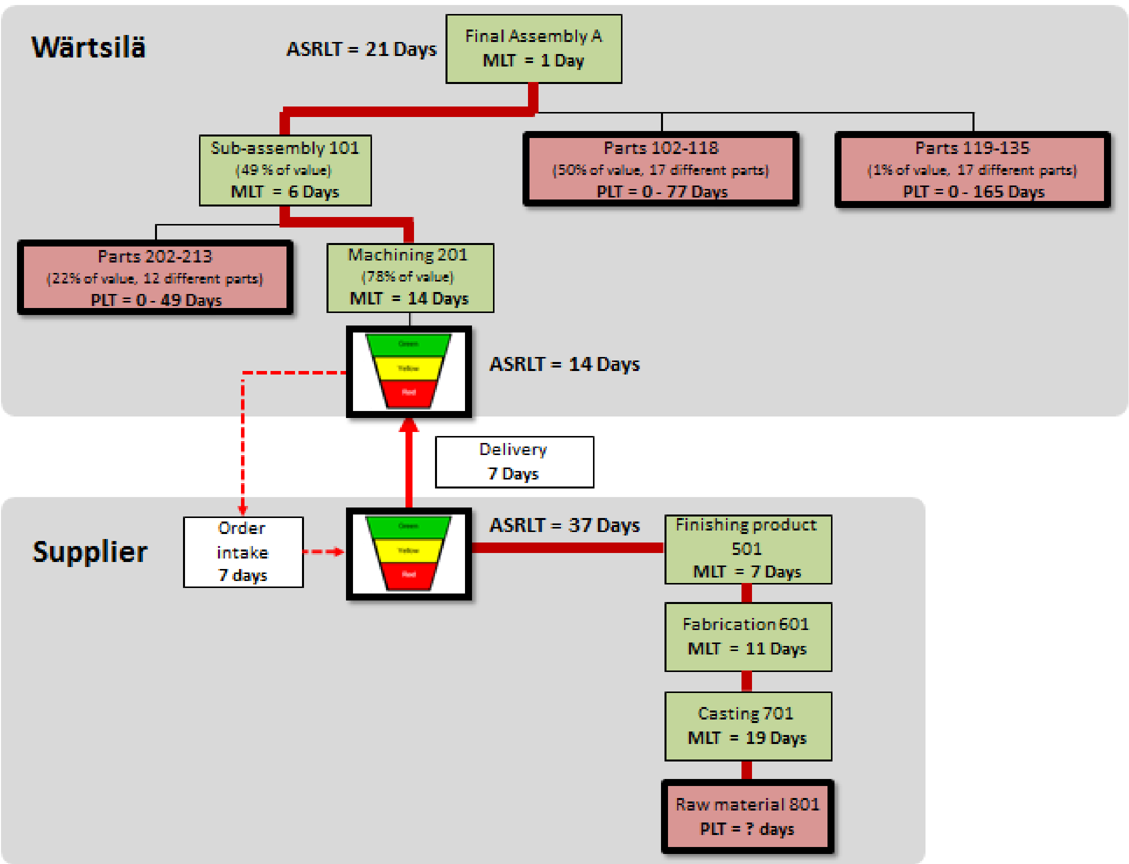


Figure 43: Optimal inventory positioning for case component

Table 6: System wide inventory comparison

System wide inventory comparison				
	Variant 1	**Variant 2**	**Variant 3**	**Variant 4**
Current total inventory (Supplier FG + Wärtsilä inbound)				
Current FG (Calculated)	105 pcs / 109 k€			
Current inbound (Actual)	1441 pcs / 1525 k€			
Total current system	**1 546 pcs / 1 634 k€**			
Current FG (Expected)	263 pcs / 273 k€			
Current inbound (Actual)	1441 pcs / 1525 k€			
Total current system	**1 616 pcs / 1 707 k€**			
DDMRP with ASRLT 61 days (MTO)				
Change in FG ASRLT 63 days (MTO)	*No changes*			
Change in inbound ASRLT 63 days (MTO)	-579 pcs / 640 k€			
System wide reduction	**-579 pcs / 640 k€**			
DDMRP with ASRLT 14 days (MTS)				
Change in FG Calculated	+ 355 pcs / 367 k€			
Change in FG Expected	+ 197 pcs / 204 k€			
Change in inbound ASRLT 14 days (MTS)	-943 pcs / 1.013 k€			
System wide reduction (With calculated current FG)	**-589 pcs / 645 k€**			
System wide reduction (With expected current FG)	**-746 pcs / 809 k€**			
ASRLT 14 d (MTS) vs ASRLT 61 d (MTO)				
Difference: MTS-MTO (With calculated current FG)	**-10 pcs / 5 k€**			
Difference: MTS-MTO (With expected current FG)	**-167 pcs / 168 k€**			

4.1.2 Buffer profiles and levels of case 1

The buffer profiles of case component are classified separately for both strategic decoupling buffers held in Wärtsilä purchase part and in supplier finished goods stock. Even though parts held in both stocks are the same the buffer profiles are not due to different factors affecting to buffer profile determination. Buffer profile of Wärtsilä strategic decoupling buffer is classified as “P30 MOQ” and for the Supplier the profile is classified as “M31 MOQ”. Both of these profiles are indicated with grey background in Table 7 below.

Buffer profile “P30 MOQ” is given based on the four factors affecting to buffer profile: item type, variability, lead time and minimum order quantity. First factor, item type, is easiest to determine and for this buffered part it is P because the part is purchase item. Variability factor is analyzed from demand and supply perspective. The demand variability is defined by calculating coefficient of variation (CV) from the past component weekly consumption history in Wärtsilä side for each four different SKUs of strategic decoupling buffer. Supply variability can be considered from on time delivery (OTD) and quality perspective where the OTD rate is expected to be high due to buffering on supplier side while the quality rate is taken from actual quality defect ratio statistics for each SKU. The variability factor for buffer profile is defined by combining demand variability – CV – with the supply variability – defect ratio – into one percentage value for each SKU where the result show that all of the SKUs has high variability factor (= 3) ranging between 65% and 103%. The lead time factor is defined low (= 0) because of the supplier MTS strategy which reduces lead time to 14 days which in the case environment is really low compared to other purchase items. The last factor is valid for this buffer profile because the SKUs has minimum batch size of 64 pieces per delivery, determined by one full truck load, which gives the “MOQ” mark in the profile

Buffer profile “M32 MOQ” of the strategic decoupling buffer on supplier side is determined with the same four factors. The parts in supplier finished goods stock are manufactured parts and hence indicated as “M” profile parts. The demand variability for these parts is the same as for the Wärtsilä purchase part and hence coded with number 3.

The main difference to P30 MOQ profile is that the manufacturing lead time 37 days is relatively long which gives lead time factor of “2” for the buffer profile. The manufacturing process contains also minimum batch size of 96 pcs for each production run which gives “MOQ” designation for manufactured part M11. One opportunity for reducing required inventory investment on M32 MOQ would be to investigate whether the given 96 pcs MOQ could be reduced at least to 64 pcs or below.

Table 7: Buffer profiles for both strategic decoupling buffers of case component

		Manufactured = M	Purchased = P	Distributed = D		
Variability	Low = 1	M10	P10	D10	Short = 0 Medium = 1 Long = 2	Lead time
		M11	P11	D11		
		M12	P12	D12		
	Medium = 2	M20	P20	D20		
		M21	P21	D21		
		M22	P22	D22		
	High = 3	M30	P30	D30		
		M31	P31	D31		
		M32	P32	D32		
MOQ Application		M10 MOQ	P10 MOQ	D10 MOQ	MOQ Application	
		M11 MOQ	P11 MOQ	D11 MOQ		
		M12 MOQ	P12 MOQ	D12 MOQ		
		M20 MOQ	P20 MOQ	D20 MOQ		
		M21 MOQ	P21 MOQ	D21 MOQ		
		M22 MOQ	P22 MOQ	D22 MOQ		
		M30 MOQ	P30 MOQ	D30 MOQ		
		M31 MOQ	P31 MOQ	D31 MOQ		
		M32 MOQ	P32 MOQ	D32 MOQ		

The buffer zones for both decoupling buffers are calculated by using the buffer zone calculation formula defined in DDMRP theory (Ptak & Smith, 2011, pp. 412-413). The zone calculation is performed by using actual consumption history from Wärtsilä side by using weekly level demand instead of daily level. Reason for using weekly time buckets for buffer zone calculation is due to the production environment where the buffer replenishment is in most of the cases performed on weekly basis for majority of purchase parts. By using the average daily usage (ADU) most of the buffer zones would become unfeasible low which might place the buffers in risk of stock out due to weekly replenishment. Hence the buffer zone calculation utilizes average weekly demand (AWU) instead of ADU when also lead times are presented in weeks instead of days.

Table 8: Buffer zones of P30 MOQ

	SKU	Variant 1	Variant 2	Variant 3	Variant 4
Factors of buffer profile	**1. Buffer profile**	**P30 MOQ**	**P30 MOQ**	**P30 MOQ**	**P30 MOQ**
	2.1 Demand Variability (CV)	**65%**	**102%**	**71%**	**54%**
	2.1.1. Average weekly usage	67	25	17	37
	2.1.2. STD	44	25	12	20
	2.2. Supply variability	**Low**	**Low**	**Low**	**High**
	2.2.1. OTD	High	High	High	High
	2.2.2. Scrap rate %	0,10%	0,85%	0,18%	19,44%
	3. Lead time in weeks	**2,0**	**2,0**	**2,0**	**2,0**
	4. MOQ	**64**	**64**	**64**	**64**
	Variability factor used	65%	103%	71%	74%
	Lead time factor used	**70%**	**70%**	**70%**	**70%**
Calculated buffer zones	*Average on hand position*	*202*	*102*	*72*	*122*
	Green zone	94	64	64	64
	Yellow zone	134	49	33	74
	Red zone base	94	34	23	52
	Red zone safety	61	35	17	38
	SKU	**Variant 1**	**Variant 2**	**Variant 3**	**Variant 4**
	TOG	383	183	138	228
	in %	100%	100%	100%	100%
	TOY	289	119	74	164
	in %	75%	65%	53%	72%
	TOR	155	70	40	90
	in %	40%	38%	29%	39%

Table 9: Buffer zones of M32 MOQ

	SKU	Variant 1	Variant 2	Variant 3	Variant 4
Factors of buffer profile	**1. Buffer profile**	**M32 MOQ**	**M32 MOQ**	**M32 MOQ**	**M32 MOQ**
	2.1 Demand Variability (CV)	**65%**	**102%**	**71%**	**54%**
	2.1.1. Average weekly usage	67	25	17	37
	2.1.2. STD	44	25	12	20
	2.2. Supply variability	**Low**	**Low**	**Low**	**High**
	2.2.1. OTD	High	High	High	High
	2.2.2. Scrap rate %	0,10%	0,85%	0,18%	19,44%
	3. Lead time in weeks	**5,3**	**5,3**	**5,3**	**5,3**
	4. MOQ	**96**	**96**	**96**	**96**
	Variability factor used	65%	103%	71%	74%
	Lead time factor used	**20%**	**20%**	**20%**	**20%**
Calculated buffer zones	*Average on hand position*	*165*	*101*	*78*	*116*
	Green zone	96	96	96	96
	Yellow zone	354	130	88	195
	Red zone base	71	26	18	39
	Red zone safety	46	27	13	29
	SKU	**Variant 1**	**Variant 2**	**Variant 3**	**Variant 4**
	TOG	567	279	215	359
	in %	100%	100%	100%	100%
	TOY	471	183	119	263
	in %	83%	66%	55%	73%
	TOR	117	53	30	68
	in %	21%	19%	14%	19%

4.1.3 Dynamic adjustment of case 1

As described in theory chapter the dynamic adjustment in DDMRP system contains three different types of adjustments: *"recalculated adjustments, planned adjustments and manual adjustments*" (Ptak & Smith, 2011, p. 423) which to use for adjusting defined buffer levels and zones. With the case component the *recalculated adjustment* by using *ADU based adjustment* is chosen for the best alternative which to use at beginning of DDMRP implementation. After implementation and when the planners learn how to adjust the buffers to demand peaks and downs the *planned adjustment* could be considered as an additional feature but in order to make simplified implementation in the beginning the *ADU-based adjustment* with one month recalculation frequency could be the best choice.

The four different variants of case component has different phases in their lifecycle where three of the variants are planned to be phased out and replaced with the fourth type of variant due to improved component standardization with the new platform engines. This change in product design affects also in the demand of the different variants where the consumption of variants 1-3 are forecasted to decline since the variant 4 will take over the consumption when new platform engines get into serial production. Since the product transition will not certainly happen exactly with some certain defined time horizon the *planned adjustment* is not feasible to be used but instead the *ADU-based adjustment* would provide more robust alternative for dealing with the product transition. In this specific production environment the new product introduction is relatively slow process and hence the planners should be capable to adjust the buffers based on changes in ADU. If there would occur sudden increase or decrease in demand of single variant the planner should be capable to make manual adjustment into buffer zones based. Figure 44 below illustrates the product transition planned to happen with variants 1-4.

Variant 1	**Variant 2**	**Variant 3**	**Variant 4**
567 100%	279 100%	215 100%	359 100%
471 83%	183 66%	119 55%	263 73%
117 21%	53 19%	30 14%	68 19%

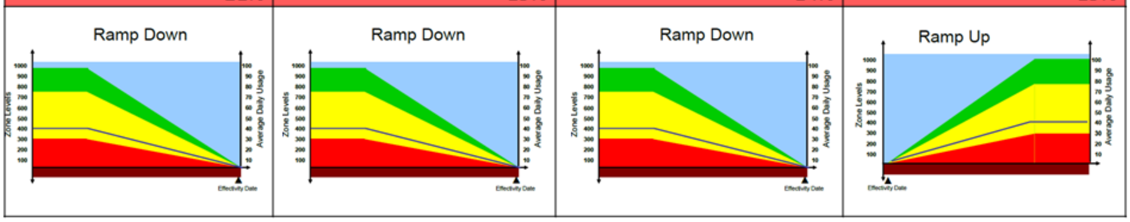


Figure 44: Product transition with case component variants 1-4

Since the case component is delivered once per week, the buffer profiles are calculated with weekly demand and because the consumed volumes on daily level are not significant the average weekly usage (AWU) could be used instead of average daily usage (ADU) for buffer adjustment. In order not to put too much time and effort on buffer profile adjustment the buffer zones could be recalculated on monthly basis by using the materialized weekly demand of last two months. If the proposed buffer zones would be significantly different than current TOG, TOY and TOR, then planner could change manually the size of the zones according proposal calculated with latest AWU values. If the AWU would be calculated based on only one month records there would be high risk that buffer adjustment would become over-reactive and hence at least two months horizon would be desirable to have. These defined recalculation horizons and frequencies could be changed after the first six months of using DDMRP according to planner’s feedback if the adjustment would be too frequent or too over- or under-reactive.

After the pilot would be performed with case component the buffer adjustment feature should be built into actual system by using the feedback collected from the pilot implementation. In the pilot implementation the AWU recalculation should be done manually in excel spreadsheet by using the consumption data collected from ERP system which company is using. This consumption data could be translated into pivot table into weekly consumption which could be used on buffer zone calculator excel created during this study for the case component. By comparing the new values with latest AWU into results and zones calculated in previous sub-chapter the planner could decide if to continue with initially defined zones or if the zones should be adjusted according to latest information. Figure 45 below illustrates the excel calculator and related pivot table – created for AWU and buffer zone calculation during this study – which could be used on the pilot implementation for the buffer adjustment.

Calculated buffer zones				
Average on hand position	*202*	*102*	*72*	*122*
Green zone	94	64	64	64
Yellow zone	134	49	33	74
Red zone base	94	34	23	52
Red zone safety	61	35	17	38
SKU	**Variant 1**	**Variant 2**	**Variant 3**	**Variant 4**
TOG	383	183	138	228
in %	100%	100%	100%	100%
TOY	289	119	74	164
in %	75%	65%	53%	72%
TOR	155	70	40	90
in %	40%	38%	29%	39%

Movement type (All)

Sum of Quantity in UnE	**Column Lat**				
Row Labels	**Variant 1**	**Variant 2**	**Variant 3**	**Variant 4**	**Grand Total**
2014	**-1609**	**-295**	**-184**	**-849**	**-2937**
1	-12				-12
2	-68	-30		-20	-118
3	-93			-24	-117
4	-129	-101	-15	-18	-263
5	-48		-46	-28	-122
6	-80	-2	-3	-8	-93
7	-62	-30		-56	-148
8	-14			-19	-33
9				-55	-55
10	-14	-16		-53	-83
11	-102	-15		-65	-182
12	-21	-4		-61	-86
13	-2	-21	-8	-34	-65
14	-49	-11	-9	-34	-103
15	-20			-87	-107
16	-56			-36	-92
17	-126		-28		-154
18	-92		-25	-10	-127
19	-26	-33	-20	-64	-143
20	-78	-8	-12	-38	-136
21	-102		-12	-34	-148
22	-50		-6	-10	-66
23	-96	-24		-28	-148
24	-181			-34	-215
25	-88			-33	-121
Grand Total	**-1609**	**-295**	**-184**	**-849**	**-2937**

Figure 45: Buffer zone calculator

4.1.4 Results for cases 2 and 3

For the case 2 the inventory positioning is presented in Figure 46 where is shown an overview of the current supply chain where the current product delivery strategy is *purchase, plan and make-to-order* where the delivery lead time for parts varies between

14-17 where is added 1 week transportation time from supplier to Wärtsilä. In the future state the supply chain would be decoupled for *assemble-to-order* strategy where the decoupling point inventory would be managed with strategic replenishment buffer. The buffer would contain the parts where the lead time is too long for enabling 6 weeks delivery lead time for the complete part. Short lead time sub-components could be still managed without DDMRP buffer and be purchased to order. Second strategic buffer would be place on the Wärtsilä inbound storage where the buffer would lead time managed type of buffer. This would mean in practice that the complete part supplied by the supplier would be ordered directly to engine assembly of Wärtsilä because of great variety of different customer specific variants when the replenishment buffer would not be feasible alternative for 22 different stock keeping units required in this buffer position. The supplier stock which should be replaced with the replenishment buffer is indicated with blue circle in the current state and Wärtsilä inbound stock which should be replaced with the lead time managed buffer is shown with red circle.

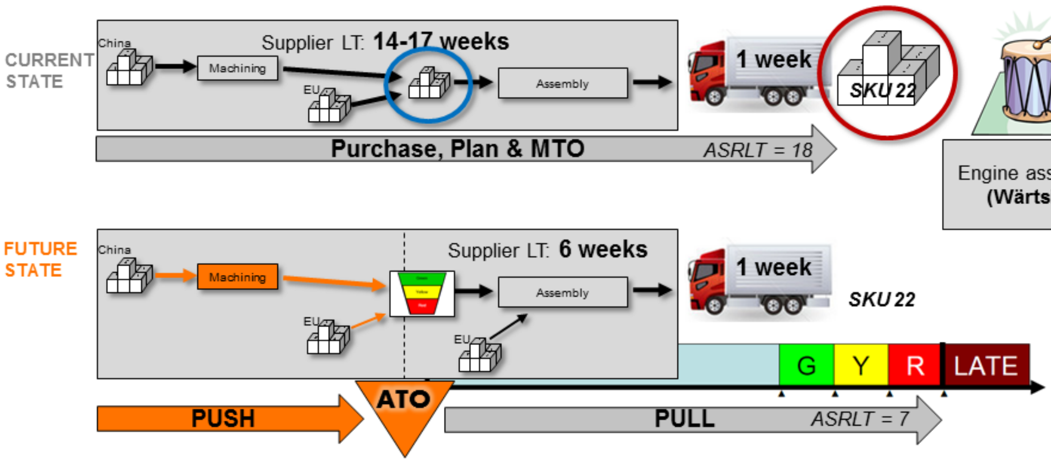


Figure 46: Inventory positioning for case 2

Figure 47 presents similar way the current and future state for the case 3 purchase parts and supply chain. For this supply chain similar inventory and buffer positioning is advised as for the case 2. Since the production produces is not an assembly process but a process manufacturing where the final product is configured from the intermediate stock according to customer order and specification. Since the production process time is difficult to shorten to enable 7 weeks ASRLT the intermediate buffer in the process would be most feasible solution since there occurs certain specification and variation after this point. With this case there are 23 different SKUs which are manufactured for Wärtsilä when the replenishment buffer wouldn't be feasible solution in the inbound storage. Another reason is that this purchase part is one of the most expensive parts of the whole engine BOM and the part is physically difficult to store due to large size. By placing the lead time buffer for the product delivery process the parts could be managed with *configure-to-order* strategy from the defined decoupling point.

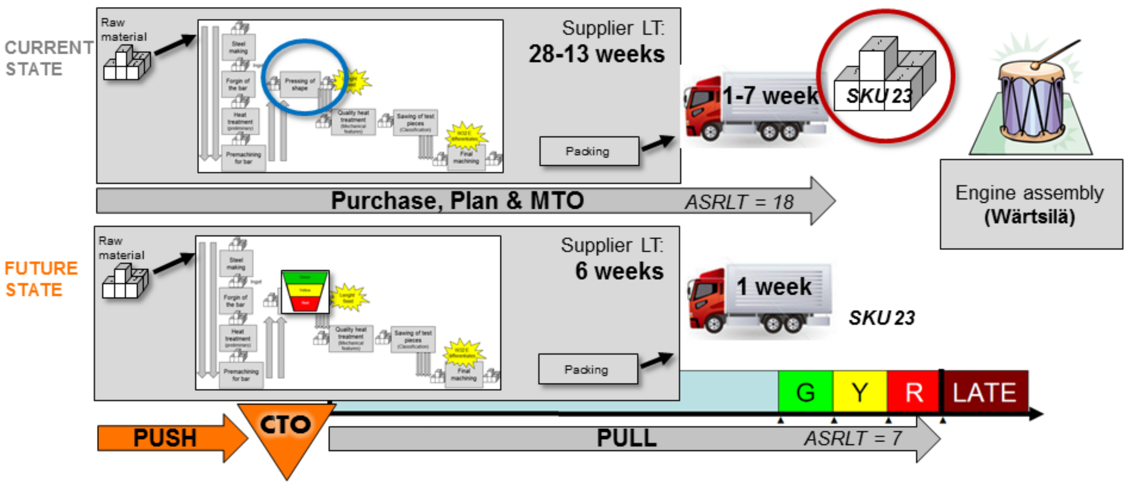


Figure 47: Inventory positioning for case 3

The detailed results of buffer profile and level calculations are presented in the appendix for the replenishment buffers explained above. In these calculations is calculated a scenario where there would be replenishment buffer in the Wärtsilä inbound storage instead of lead time managed buffer in order to understand what size of average inventory would be needed in case the company would pursuit replenishment buffer instead of lead time managed buffer. For the case 2 the interviewed person had BOM information available for one of the three suppliers supplying the case parts which information was used for calculating the buffer zones for the intermediate replenishment buffer which would be needed in the supplier side for the long lead time parts. For the rest of the suppliers the intermediate replenishment buffer zones should be calculated together with the supplier with the BOM, related lead times and inventory routing information. Also for the supplier where this information was available it is advised to follow the implementation process explained in next chapter when creating the actual buffer zones for the intermediate stock. The results shown in the appendix could be used as a reference example what the buffer zones could be based on the information what was available during this research.

The dynamic adjustment would be best to follow similar steps as what explained for the case 1. Since the planned product transition is likely to affect also for the stock keeping units for cases 2 and 3 the effect for replenishment buffers should be considered together with the suppliers. Since the intermediate buffers are likely to be non-customer specific parts there is great potential for inventory risk pooling when the possible product transitions doesn’t necessary even effect on the replenishment buffer consumption if the intermediate SKUs can be used for multiple different product variants. At least for the case 3 replenishment buffer the intermediate SKUs are similar for all different engine platforms when the planned product transition in Wärtsilä would not have any effect on the zone calculations.

4.2 Project proposal for case company

This sub-chapter presents a project proposal how the case company Wärtsilä 4-Stroke could continue after pre-study to the actual DDMRP implementation. The purpose of this project proposal is to give practical suggestion for the case company how they could implement a *collaborative DDMRP system* which would enable the supplier and supply chain integration and synchronization in their non-vertically integrated supply chain by using the collaborative planning, forecasting and replenishment (CPFR) concept where DDMRP logic would be embedded as the controlling philosophy of the CPFR system. The case company uses standardized gate model framework for operational development (OD) projects which should be used also for this type of development project. Hence the supply chain collaboration and CPFR implementation models by Christopher (2011) and Ireland (2005) explained in the theory chapter are adjusted to fit into the gate model guidelines of the case company.

In the Wärtsilä project gate model framework all type of projects are divided into five phases: *explore, initiate, plan, execute* and *close*, where each project phase is assessed with five main gates*: G0, G1, G2, G3 and G4*, before the next phase is authorized to be started. Purpose of these gates is to decision point where is assessed if the project can be continued or not based on the gate decision performed by project owner, or by project owner together with defined steering committee. Gate assessment usually contains analysis of what has been achieved during previous phases, is the achievement aligned what was planned in previous gate, what are the needed resources for the next phase, what are the deliverables from next phase, is the project proceeding according to desired solution and can the decision maker ensure that project has the required resources available for the next project phase. In the OD projects the execution phase is divided into three sub-phases called *develop, validate and deploy,* where the sub-phases are controlled with two sub-gates called *G2A* and *G2B*. Usually in OD projects the main investments are assessed and approved in G2, before solution development and pilot implementation, and in G2B before the deployment of piloted solution.

Figure 48 below illustrates high level project plan for collaborative DDMRP implementation project where the *proven path* (Ireland, 2005) and *five components of DDMRP* (Ptak & Smith, 2011, p. 390) are embedded into Wärtsilä OD project gate model phases and gates. In the illustration below the main focus is on project initiation, planning, solution development and pilot implementation. The main idea with this approach would be to first create proper awareness and *commitment* (Ireland, 2005) before proceeding into actual DDMRP solution implementation. Important step in the commitment, or *"pre-time-zero"*, steps is to recognize and choose the appropriate relationship management style and sourcing approach for each specific supplier relationship where the collaborative DDMRP system is considered to be implemented. Another main purpose of commitment phases before G2 is to establish thorough understanding in the relevant management persons, which would be also the project steering committee, what is targeted with such collaborative initiative, why the change is needed, how the change is going to be achieved and how the project performance is measured. Only after these important aspects are understood are decided the actual collaborative DDMRP implementation can begin with the *"post-time-zero"* phases.

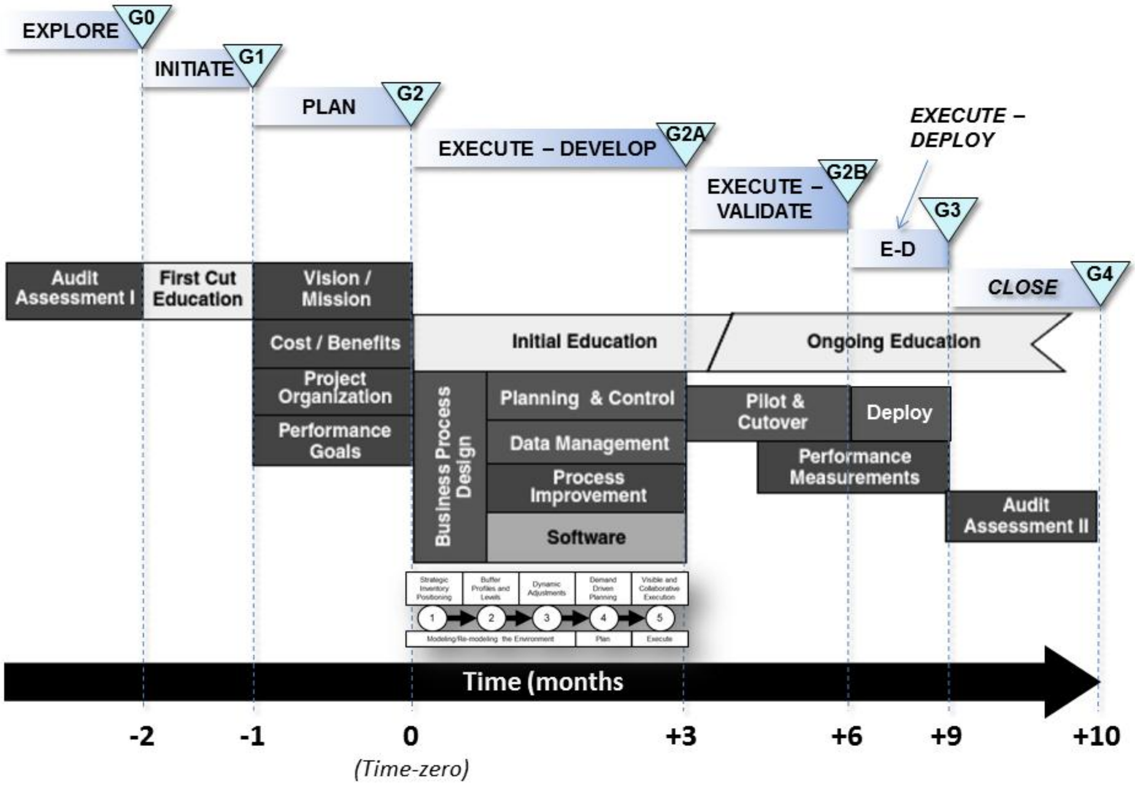


Figure 48: Proven path (Ireland, 2005) and five components of DDMRP (Ptak & Smith, 2011, p. 390) embedded within Wärtsilä gate model

In the exploring phase company's supply chain and related suppliers would be analysed in a high level where would be selected which parts could be feasible to manage with DDMRP logic. During this phase also the organisational unit should be selected where would be potential interest on demand driven MRP piloting and into supply chain integration which should lead to improved responsiveness and higher ROI for the unit and its supply chain partners. For the case company the *collaborative DDMRP* implementation would be best to start with limited scope and not to push the system directly to all manufacturing units without first testing the suitability in the selected pilot unit. During the exploration the selected unit should create assessment of their current collaboration and material synchronization status which could be compared to benchmark companies who had adopted DDMRP system or collaborative practises.

The G0 should be presented to management level which is capable to assign required resources for the *project initiation*, *planning* and *execution phases*. The G0 presentation should be held by the business champion who would be the project owner for the collaborative DDMRP implementation project in the selected unit. Also the required steering committee, project manager and group of relevant key persons required for the initiation phase should be nominated and presented in the G0 where the management can either approve or decline the utilization of their resources for the project initiation. Also the required investment for the first cut education session should be presented in G0 as a part of the project business case for the initiation phase. The presentation could also include a first relatively high level business case what could be achieved from DDMRP implementation and supply chain collaboration. For this G0 business case the initial results from the earlier pre-study could be used to illustrate the inventory reduction potential calculated for the case components 1-3 in conjunction with first estimate on how the ROI could be improved after the supply chain synchronization with collaborative DDMRP implementation.

If the G0 would be approved by the management, the project could continue into the *initiation phase* where the main purpose is to educate the required key resources on how the collaborative DDMRP could be implemented, how the DDMRP system differs from conventional MRP, what are the benefits of supply chain collaboration and what the implementation in conceptual level would mean in their own responsibility area. During the initiation phase the current supplier relationship management styles, power regimes and so far used sourcing options should be identified by the category managers who are in response of the suppliers and purchase parts in the scope of collaborative DDMRP implementation. After the current practice is identified there should be defined the appropriate relationship management style for each supplier who are supplying the purchase parts which are selected for the scope of the DDMRP implementation. Other key topics in the initiation phase would be to identify lessons learned from other companies, understand the requirements from resource and technology perspective and identify what are the next steps in the project together with appropriate time schedule.

These and the other main topics from above should be presented by the project manager in the G1 for the project owner and for the steering committee of the project who decides if the project has clear objectives and if the organisation has sufficient resources for the next phase.

After G1 the project enters into the *planning phase* where needs to be defined ***vision/mission*** of the project, detailed ***cost/benefit*** calculations to be modified into the business case, ***project organisation*** to be set-up for the execution phase and project ***performance goals*** to be outlined. ***Vision/mission*** is basically the definition what the company or the collaborative companies want to achieve from the collaborative DDMRP implementation. In case of arms-length relationship management style the company generates the vision/mission solely while for the collaborative relationships company generate the vision/mission together with the supplier. Important part of the vision/mission part is to identify what are the key milestones in the project execution.

Detailed ***cost/benefit*** calculations are quiet much dependent on the appropriate relationship management style what is selected to be used for the suppliers in the scope of the project. For the collaborative non-adversarial relationships the open book accounting is preferred to be used together with the supplier for target setting what could be achieved with the collaborative DDMRP system in purchase part selling price, total inventory cost and lead time reductions. For the other types of relationships the buying company could try to utilize the open book accounting for calculating the selling price targets but if the supplier is not willing to open their cost structures the targets could be set based on best estimate what company can make on the impact on cost structure. For the collaborative relationships the above mentioned targets would be best to set together with the supplier while for the arms-length relationships the buying company is advised to implement DDMRP system only in the internal operations and not to extend the system into the upstream supply chain when also the targets can be set only on the own inventory cost reduction. The defined targets need to be consolidated into single benefit calculation which would be linked to company’s financial statement and balance sheet when the ROI potential could be calculated for the buying company and also for the collaborative suppliers. Another aspect in the cost/benefit calculation is to estimate what the implementation would cost for the company where needs to be defined if the investment would be paid solely by buyer company or if the collaborative suppliers would carry their proportion from the cost since they will get also part of the benefit.

Project organisation set-up means clarifying who is leading which DDMRP implementation stream. Example the arm-length supplier relationship stream team leader could come from operational purchasing since in this stream the system is advised to be implemented only for the internal operations. For the collaborative supplier relationship stream the team leaders should come from sourcing organisation. For the internal operations stream the team leader should come from the manufacturing organisation and be person who has direct control on the manufacturing process of the parts in the scope of the project. Other possible streams could be the technology integration stream where the team would be leaded by person who has thorough understanding on the information technology integration needed inside the organisation and between the collaborative partners. Important in the project organisation set-up is to build the teams and team leaders from the company own personnel who understand the practical implications of the system and who would have the control of the system after it is implemented. Possible support resources or consultants can be assigned for team support but those shouldn't be assigned on leading any stream since then there is a risk of creating *not-invented-* and *not-applicable-in-here* type of solution.

Performance goals are defined for monitoring the project proceeding and success criteria. It is possible that performance goals can be measured with existing performance measurement system what company is using. If the existing measures don't comply with project targets then temporary measurement system needs to be established with responsible person for creating the measurement. Shared performance goals should set for the whole project and those can be linked into the financial impact what the project should deliver. In addition to common goals the individual project streams requires own performance goals which should be linked into the success criteria set for each stream. To help project manager, stream team leaders and team members to maintain focus on the project work during the implementation some compensation system could be defined and linked to common project and individual stream performance goals.

When all of these four steps in the project planning phase are clarified the project enters into the G2 which is also the *"time-zero"* point between the *commitment* and *execution* phase of implementation project. In the G2 the detailed business case is evaluated and the project payback is evaluated. The steering committee evaluates if the project has met the required criteria for G2 assessment and after that gives go decision if the project execution is seen beneficial. For the collaborative stream the team leader should review after the G2 approval the stream specific project execution plan together with the key decision makers from the collaborative suppliers who should decide if the collaboration project can be continued or not. Hence also the key persons from the supplier company should be capable to assign needed investment and human resources for the execution phase if the go decision is given. After the G2 is approved internally and externally with collaborative suppliers, starts the *execution phase* which has three sub-phases of *develop, validate and deploy*. During the execution phase the five components of DDMRP system is piloted and implemented for the parts, supply chains and suppliers in the scope of project. For the execution phase of the collaboration stream the *VICS-ECR nine-step CPFR model* is modified to support the collaborative DDMRP implementation where the five components of DDMRP are defined together with buyer and supplier according to steps shown in Figure 49 below. In the figure is shown what would be the ideal contribution or proposal to each component of collaborative DDMRP system, how each of the components is expressed in the *proven path* and how these steps would fit into "*execute – develop"* phase of the project gate model.

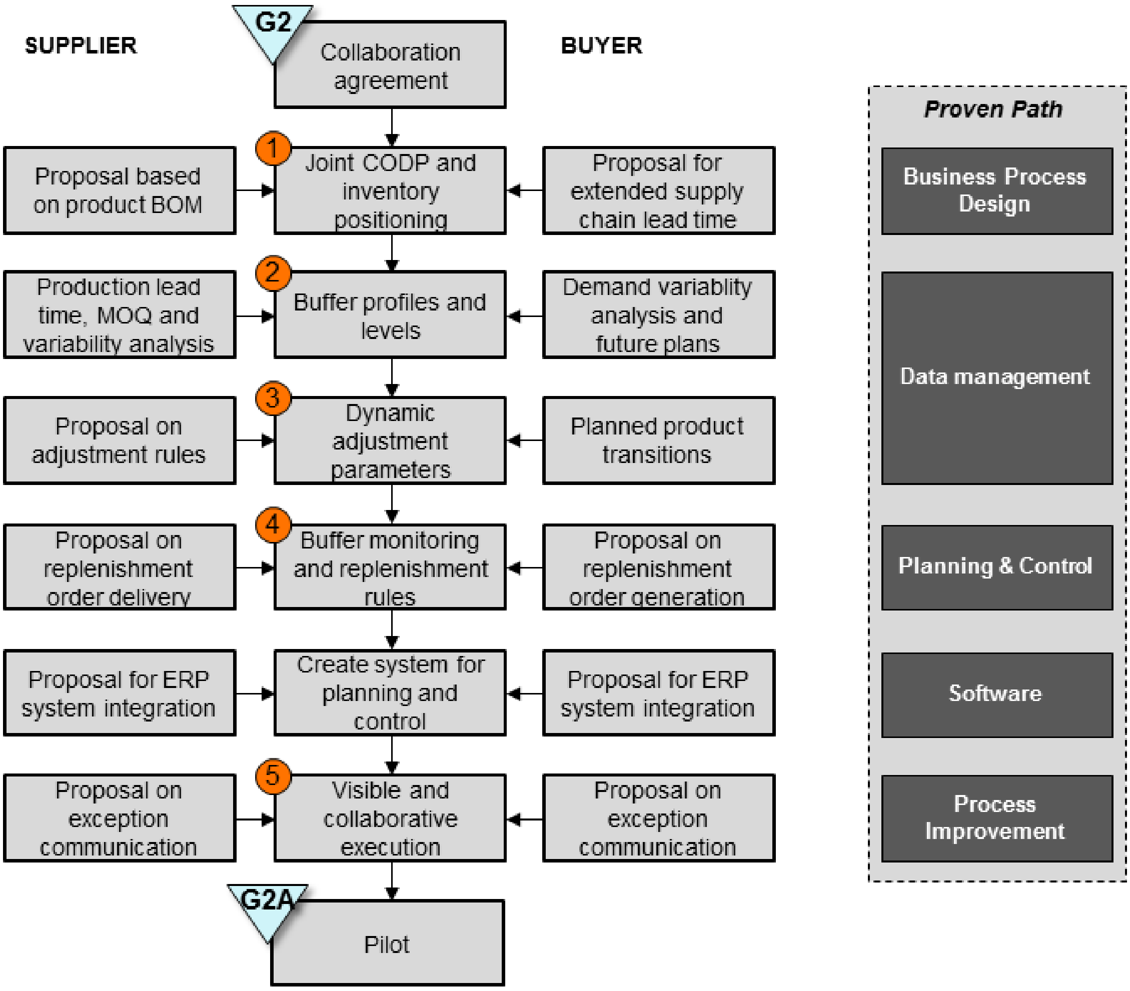


Figure 49: The five components for collaborative DDMRP implementation

The collaborative DDMRP system should be defined and developed between G2 and G2A where the collaboration agreement step would be created after the internal G2 approval together with the supplier company. The pilot phase would begin after the system would be defined according process described above and after the G2A would be approved by the project steering committee and by the supplier company. Other elements needed for G2A decision point are the cost and resource estimate required for the piloting phase. Possible costs for the piloting phase are training costs for the system users, cost of running the technological solution and possible investments to new technology if not invested earlier.

After the G2A is approved starts the piloting phase labelled as *"execute – validate"* in the project gate model. Ireland (2005, pp. 180-181) propose three pilots where the defined collaborative system is first piloted with minimal new technology to first test the people and process issues related to roles, responsibilities, accountabilities and trust. After the possible issues are fixed the second pilot is conducted where the new technological system is tested for the selected pilot components. After the first and second pilots are successfully implemented the system is scaled for the full product scope what the supplier is providing. Similar three stage pilot/cutover is proposed for this "*execute – validate"* phase of this project related to collaboration stream. After the possible issues are identified and corrective actions are taken can the new technology execution be extended to the full product scope what supplier is providing. Hence the collaboration stream could have own decision point between the first pilot and the second and third pilot described above. In this decision point is assessed the cost and resource needs for implementing the new technology for the full product portfolio what the supplier is providing for the buyer company.

After the validated collaborative DDMRP system is implemented for the selected supplier relationships the project enters to G2B decision point where company's steering committee evaluates was the pilot projects in the different streams successful or not. In case those has been successful based on the performance criteria defined earlier the similar approach is decided to be used for other potential parts, supply chains and supplier relationships. In the G2B is evaluated what was the cost of pilot implementation and that is used as the basis for calculating the needed money and resources for the deployment phase where the system is extended to cover the full product portfolio in the selected business unit. The deployment phase should follow similar steps as what has been made during the G1-G2B in case there is lot of persons who were not involved in the initial project scope. If the G2B is approved the project enters into the "*execute – deploy"* phase of the gate model.

After the collaborative DDMRP system is successfully implemented for the case company unit the project enters into the G3 decision point where is evaluated how the project execution performed compared to defined targets in the beginning of execution. After the G3 project enters in the *closing* phase where is audited how much the project actually needed money and resources for execution and what benefits was realized during the project. Possible gaps are evaluated and further improvement opportunities are listed. Important step in the closing phase is to arrange lessons learned session with key stakeholders which results should be recorded in the project report. The report can be used for possible extension of the project and collaborative DDMRP implementation in the other business units of the case company with a proposal how it could be done.

One important step during the project implementation is the establishment of key performance indicators (KPIs) which support the new way of managing the supply chain with collaborative DDMRP. In some cases the company might be capable to continue with existing KPIs but most likely new flow based measures are needed to ensure that company is measuring and driving continuous improvement on information and material flow which support the system primary goal of maximizing the ROI. In figure below is presented framework what could be used for creating KPIs to different organisational levels by using *value based management* principles where the value drivers are defined to support DDMRP managed flow management. In the figure the KPIs are presented with white boxes, organisational level with grey shaded areas and orange boxes illustrate explaining factors between the different level KPIs.

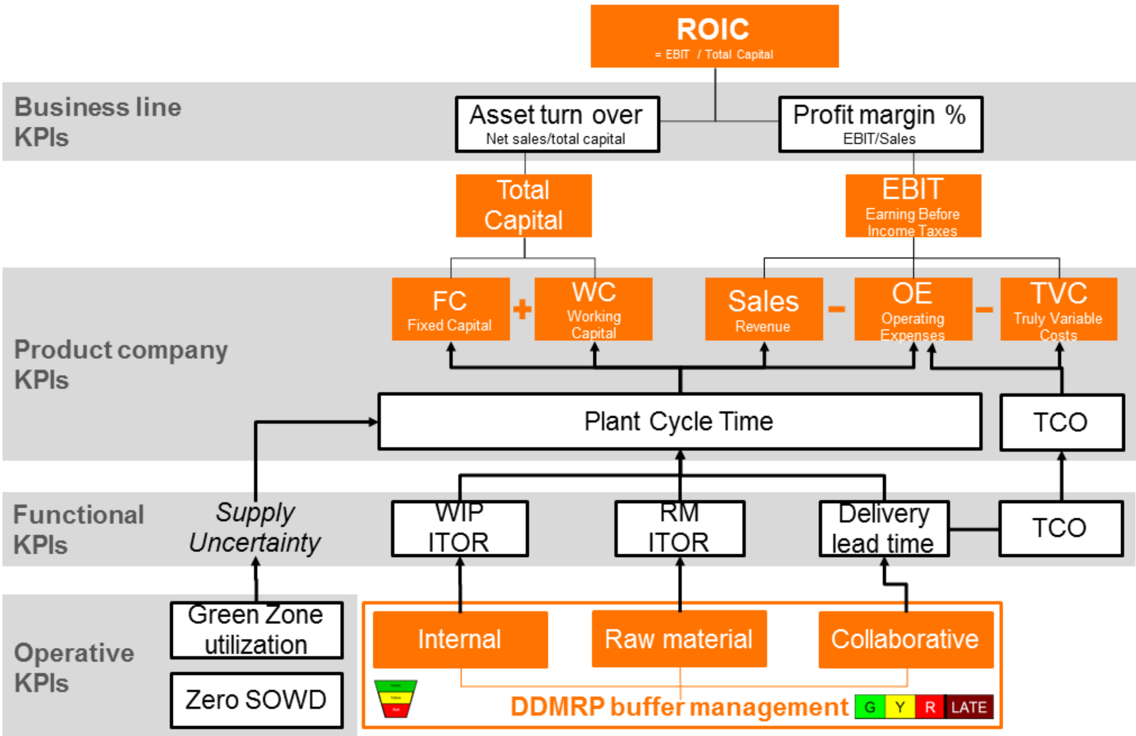


Figure 50: KPIs for DDMRP managed supply chain system

5. CONCLUSION

For the first research question, *how the supply chain synchronization with DDMRP implementation could improve responsiveness and lower inventory cost*, the results show that by improving the visibility and creation of robust pull based DDMRP managed CONWIP solution the case company could lower 47% the inventory holding costs for a single case part by reducing 809 000 € worth of inventory from the current 1 707 000 € inventory holding while at the same time the responsiveness could be improved with shorter market response time. By extending the DDMRP system for the extended supply chain the responsiveness could be improved by having lower inventory holding in the interfaces between buying and supplying company. The expected benefits of such collaborative DDMRP implementation project would be the flow improvement throughout the chain which would lead to lower operating expenses and higher sales for both trading partners when the return of investment (ROI) could be improved on both sides of the supply chain relationship. This extended ROI improvement in the supply chain would generate more value for both companies and enable the supply chain to compete with less pipeline inventory, lower total expenses and with improved market responsiveness.

For the second research question, *how to implement DDMRP in non-vertically integrated supply chain*, the result is designed in a form of collaborative DDMRP implementation project proposal which is based on the five components of DDMRP. Purpose of the collaborative DDMRP implementation model is to integrate the strategic suppliers closer to the buying company which would enable creation of synchronized supply chain which would lead to higher responsiveness, lower inventory holding costs, lower operating expenses and to improved ROI performance. For the selection of potential partners for such collaborative DDMRP implementation the appropriate relationship management style by Andrew Cox (2004) is applied before entering into the five steps of DDMRP implementation. For the non-collaborative arms-length relationships the DDMRP implementation is suggested to be limited into internal operations and related raw material and working progress inventories. In such case the purchase order generation for raw material inventory and controlling of own assembly operations and related working progress (WIP) inventories would be managed with DDMRP.

The main limitation of this study is the cross-sectional nature of the study where the presented results are based on the theoretical assumptions adopted for the case environment. In order to improve the validity of the results, the case company should tests results by initiating the project proposal. After the project would be completed the results of this study could be validated with the actual ROI improvement and related value drivers. The first practical benefit of this research for Wärtsilä 4-Stroke is the pre-study on the potential benefits of DDMRP implementation in their specific environment where the method is analyzed in details for three different strategic long lead time purchase parts supplied to the production site located in Finland. Second benefit is the project proposal explained in the chapter 4.2 what company could use for initiating, planning and execution of the collaborative DDMRP implementation project in their supply chain. The next step for the case company would be to utilize the pre-study created on this research for introducing the DDMRP system and related benefits to key stakeholders before entering into the collaborative DDMRP implementation project.

The project would start with initiation phase where the system and implementation project would be introduced to key stakeholders. This phase would be followed with planning phase where the actual cost and benefit calculations would be performed for the selected scope of strategic parts where the company would implement DDMRP system. Outcome of planning phase would be detailed cost and benefit calculation and detailed plan how the DDMRP system would be taken into use in the case environment. After the planning phase would come the process and technological system design, piloting and implementation phase. In the end of the project would be evaluated did the project meet the desired performance goals by comparing the gained benefits to the required resources. After the post evaluation of DDMRP implementation, could be stated how much the company increased ROI and how the implementation affected to different drivers of ROI shown in Figure 50: *KPIs for DDMRP managed supply chain system*.

The first results from the early DDMRP adopters give promising figures for companywide return on invested capital improvement from 4% to 22% in four years.

Such results should encourage also Wärtsilä 4-Stroke to initiate the project proposal and investigate how they could benefit of this new and innovative material management concept called Demand Driven Material Requirements Planning (DDMRP). This project execution would provide great opportunity also for a scientific research to test how the DDMRP system would contribute in practice to different value drivers of improved ROI shown in figure 50.

REFERENCES

APICS, 2008. *APICS Dictionary.* 12th ed. New York: Blackstone.

Childerhouse, P. & Towill, D., 2000. Engineering supply chains to match customer requirements. *Logistics information management,* 13(6), pp. 337-345.

Christopher, M., 2011. *Logistics & Supply Chain Management.* 4th ed. Harlow: Pearson Education Limited.

Christopher, M., Peck, H. & Towill, D., 2006. A taxonomy for selecting global supply chain strategies. *The International Journal of Logistics Management,* 17(2), pp. 277-287.

Constraints Management Group, 2008. *Beyond MRP - Meeting the current materials synchronization challenge,* Enumclaw: Constraints Management Group.

Cox, A., 2004. The art of the possible: relationship management in power regimes and supply chains. *Supply Chain Management: An International Journal,* 9(5), pp. 346-356.

Drury, C., 2012. *Management and cost accounting.* 8th ed. Hampshire, UK: Cengage Learning EMEA.

Group, A., 2006. *ERP Study,* s.l.: Aberdeen Group.

Hoekstra, S. & Romme, J., 1992. *Integrated Logistics Structures: Developing Customer Oriented Goods Flow.* London: McGraw-Hill.

Holweg, M., Disney, S., Holmström, J. & Småros, J., 2005. Supply chain collaboration: making sense of the strategy continuum. *European Management Journal,* 23(2), p. 170–181.

Hopp, W. J. & Spearman, M. L., 2011. *Factory Physics.* 3rd ed. Long Grave, IL: Waveland Press, Inc..

Ireland, R. K., 2005. *Supply Chain Collaboration : An Implementation Guide.* Boca Raton, FL, USA : J. Ross Publishing, Incorporated.

Kajüter, P. & Kulmala, H., 2010. Open-Book Accounting in Networks. In: H. Håkansson, K. Kraus & J. Lind, eds. *Accounting in Networks.* Oxon, UK: Taylor & Francis, pp. 211-232.

Kapuscinski, R. et al., 2004. Inventory Decisions in Dell's Supply Chain. *Interfaces,* 34(3), pp. 191-205.

Kumar, S. & Craig, S., 2007. Dell, Inc.'s closed loop supply chain for computer assembly plants. *Information Knowledge Systems Management,* Volume 6, pp. 197-214.

Lee, H. & Billington, C., 1992. Managing supply chain inventories: pitfalls and opportunities. *Sloan Management Review,* Volume Spring, pp. 65-73.

Mason-Jones, R., Naylor, B. & Towill, D. R., 2000. Engineering the leagile supply chain. *International Journal of Agile,* 2(1), pp. 54-61.

Mather, H., 1988. *Competitive Manufacturing.* Englewood Cliffs, NJ: Prentice-Hall.

Naylor, J. B., Naim, M. M. & Berry, D., 1999. Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain. *Int. J. Production Economics,* Volume 62, pp. 107-118.

Olhager, J., 2003. Strategic positioning of the order penetration point. *Int. J. Production Economics,* Volume 85, pp. 319-329.

Olhager, J., 2010. The role of the customer order decoupling point in production and supply chain management. *Computers in Industry,* Volume 61, pp. 863-868.

Olhager, J. & Östlund, B., 1990. An integrated push-pull manufacturing strategy. *European Journal of Operational Research,* 45(2-3), pp. 135-142.

Ptak, C. & Smith, C., 2011. *Orlicky's Material Requirements Planning.* 3rd ed. USA: McGraw-Hill.

Reichhart, A. & Holweg, M., 2007. Creating the customer-responsive supply chain: a reconciliation of concept. *International Journal of Operations & Production Management,* 27(11), pp. 1144-1172.

Sanderson, J. & Cox, A., 2008. The challenges of supply strategy selection in a project environment: evidence from UK naval shipbuilding. *Supply Chain Management: An International Journal,* 13(1), pp. 16-25.

Sharman, G., 1984. The rediscovery of logistics. *Harvard Business Review,* 62(5), pp. 71-79.

Simchi-Levi, D., Kaminsky, P. & Simchi-Levi, E., 2008. *Designing and managing the supply chain: Concepts, strategies and case studies.* 3rd ed. New York: McGraw-Hill.

Smith, D. & Smith, C., 2014. *Deman Driven Performance: Using Smart Metrics.* United States of America: McGraw-Hill Education.

Speckman, R. E., Kamauff Jr, J. W. & Myhr, N., 1998. An empirical investigation into supply chain management: A perspective on partnerships. *International Journal of Physical Distribution & Logistics Management*, 28(8), pp. 630-650.

van Donk, D. P., 2001. Make to stock or make to order: The decoupling point in the food processing industries. *International Journal of Production Economics,* 69(2), p. 297–306.

van Weele, A. J., 2010. *Purchasing & Supply Chain Management - Analysis, Strategy, Planning and Practice.* 5th ed. Hampshire, UK: Cengage Learning EMEA.

Vollmann, T. E., Berry, W. L., Whybark, D. C. & Jacobs, R. R., 2005. *Manufacturing planning and control systems for supply chain management.* 5th ed. New York: McGraw-Hill.

Wade, R., Mann, I. J. S. & Rose, S., 2012. A Strategic Perspective and Taxonomy of Supply Chain Strategies. *The IUP Journal of Operations Management,* XI(3), pp. 6-42.

Wärtsilä , 2014. *This is Wärtsilä.* [Online] Available at: http://www.wartsila.com/en/about/company-management/overview [Accessed 11 November 2014].

Yin, R. K., 1994. *Case study research: design and methods.* 2nd ed. Thousand Oaks, California: SAGE Publications.

Zhou, L., Disney, S. & Towill, D. R., 2010. A pragmatic approach to the design of bullwhip controllers. *Int. J.ProductionEconomics,* Volume 128, pp. 556-568.

APPENDIXES

APPENDIX 1: Traditional MRP versus DDMRP (Ptak & Smith, 2011, p. 490)

	Typical MRP Attributes	DDMRP Attributes	DDMRP Effects
Planning Attributes	*MRP uses a forecast or master production schedule as an input to calculate parent and component level part net requirements.*	*DDMRP uses buffer profiles in combination with part traits to set initial buffer size levels. These buffer sizes are dynamically resized based on actual demand. Buffer levels are replenished as actual demand forces buffers into their respective rebuild zones. Planned adjustments are used to "flex" buffers up or down.*	*DDMRP eliminates the need for a detailed or complex forecast. Planned adjustments to buffer levels are used to known or planned events/circumstances.*
	MRP pegs down the entire Bill-Of-Material to the lowest component part level whenever available stock is less than exploded demand.	*Pegging is decoupled at any buffered component part.*	*Larger BOM environments are often stratified into independently planned and managed horizons separated by buffered positions. This prevents or dampens "nervousness".*
	Manufacturing Orders are frequently released to the shop floor without consideration of component part availability.	*Material Synchronization and Lead Time Alerts are designed to warn planners of shortfalls when incoming supply will not be in time for parent demand order release.*	*Planners can take appropriate action and eliminate excess and/or idle WIP.*
	Limited future demand qualification. Limited early warning indicators of potential stock outs or demand spikes.	*An order spike horizon in combination with an order spike threshold qualifies spike quantities over the ASRLT of the part. The qualified spike is then added to the available stock equation and is compensated for in advance.*	*Reduces the materials and capacity implications of large orders and/or limited visibility. Allows stock positions to be minimized since spike protection does not have to be "built in".*
	Lead time for parent part is either manufacturing lead time (MLT) or the cumulative lead time (CLT) for the parent item.	*DDMRP uses ASR Lead Time, which is the longest unprotected/coupled sequence in the bill of material whenever that lead time exceeds manufacturing lead time.*	*Creates a realistic lead time for customer promise and/or buffer sizing. Enables effective lead time compression activities by highlighting the longest unprotected path.*
Stock Management Attributes	*Fixed reorder quantity, reorder points, and safety stock that typically do not adjust to actual market demand or seasonality.*	*Buffer levels are dynamically adjusted as the part specific traits change according to actual performance over a rolling time horizon. Planned adjustments "flex" buffers for product phase in/out and seasonality.*	*DDMRP adapts to changes in actual demand and planned/strategic changes.*
	Past due requirements and orders to replenish safety stock can be coded as "Due Now".	*All orders get an assigned a realistic due date based upon on ASR lead times.*	*Creates a realistic lead time for customer promise and/or buffer sizing. Enables effective lead time compression activities by highlighting the longest unprotected path.*
	Priority of orders is managed by due date (if not due now)	*Al DDMRP buffered parts are managed using highly visible zone indicators including the percentage encroachment into the buffer. This gives you a general reference (color) and discrete reference (%).*	*Planning and materials personnel are able to quickly identify which parts need attention and what the real-time priorities are.*
	Once orders are launched, visibility to those orders is essentially lost until due date the order when it is either present or late.	*DDMRP gives special consideration to some critical non-stocked parts called LTM parts. These parts are given visibility and color coded priority for pre-expediting activities through lead time alerts.*	*Better synchronizes key non-stocked components with demand orders and reduces schedule surprise and sliders due to critical part shortages.*

APPENDIX 2: Current calculated average FG stock in supplier side

Current FG stock in supplier side (MTO with MRP)				
Calculated CS + SS	**Variant 1**	**Variant 2**	**Variant 3**	**Variant 4**
Direct material cost	950 €	990 €	1.140 €	1.130 €
Average weekly usage (Coefficient of Variation)	55 (0,67)	25 (1,02)	17 (0,71)	34 (0,54)
Cycle stock	34	12	8	18
Safety stock *(+50%)*	14	6	4	9
Calculated current FG stock (MTO)	48 pcs / 46 k€	18 pcs / 18 k€	12 pcs / 14 k€	27 pcs / 31 k€
Actual full WIP - Intermediate WIP = Current actual FG	N.A.	N.A.	N.A.	162 pcs - 96 pcs = 66 pcs
Total	**105 pcs / 109 k€**			

APPENDIX 3: Calculated difference in FG stock when moving from MTO to MTS

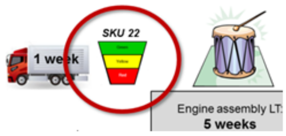
Difference in FG stock in supplier side (MTS with DDMRP)				
Calculated CS + SS	**Variant 1**	**Variant 2**	**Variant 3**	**Variant 4**
Direct material cost	950 €	990 €	1.140 €	1.130 €
Calculated current FG stock (MTO)	48 pcs / 46 k€	18 pcs / 18 k€	12 pcs / 14 k€	27 pcs / 31 k€
Total (MTO)	**105 pcs / 109 k€**			
Average FG on-hand position (MTS) - Without 96 pcs MOQ = Benefit to reduce MOQ	165 pcs / 157 k€ 152 pcs / 144 k€ 13 pcs / 12 k€	101 / 100 k€ 66 pcs / 65 k€ 35 pcs / 35 k€	78 pcs / 89 k€ 39 pcs / 44 k€ 39 pcs / 44 k€	116 pcs / 131 k€ 87 pcs / 98 k€ 29 pcs / 33 k€
= Sum of benefit	116 pcs / 124 k€			
Total (MTS)	**460 pcs / 477 k€**			
Increase in FG stock	**355 pcs / 368 k€**			

APPENDIX 4: Inbound stock after DDMRP implementation

Future inbound stock in Wärtsilä side				
Calculated with DDMRP logic	**Variant 1**	**Variant 2**	**Variant 3**	**Variant 4**
Direct material cost	950 €	990 €	1.140 €	1.130 €
Current vs DDMRP (MTS)	-257 pcs / 244 k€	-71 pcs / 70 k€	-322 pcs / 367 k€	-293 pcs / 331 k€
Actual current stock ASRLT 14 days (MTS)	459 pcs / 436 k€ 202 pcs / 192 k€	173 pcs / 171 k€ 102 pcs / 101 k€	394 pcs / 449 k€ 72 pcs / 82 k€	415 pcs / 469 k€ 122 pcs / 138 k€
Total: ASRLT 14 days	**-943 pcs / 1 013 k€**			
Current vs DDMRP (MTO)	-82 pcs / 78 k€	-11 pcs / 10 k€	-287 pcs / 327 k€	-199 pcs / 225 k€
Actual current stock ASRLT 63 days (MTO)	459 pcs / 436 k€ 377 pcs / 358 k€	173 pcs / 171 k€ 162 pcs / 161 k€	394 pcs / 449 k€ 107 pcs / 122 k€	415 pcs / 469 k€ 216 pcs / 244 k€
Total: ASRLT 63 days	**-579 pcs / 640 k€**			
MTS vs MTO (DDMRP)	-175 pcs / 166 k€	-61 pcs / 60 k€	-35 pcs / 40 k€	-94 pcs / 106 k€
ASRLT 14 days (MTS) ASRLT 63 days (MTO)	202 pcs / 192 k€ 377 pcs / 358 k€	102 pcs / 101 k€ 162 pcs / 161 k€	72 pcs / 82 k€ 107 pcs / 122 k€	122 pcs / 138 k€ 216 pcs / 244 k€
Total: MTS vs MTO	**-365 pcs / 372 k€**			

APPENDIX 5: Replenishment buffer zones for case 2 replenishment buffer in Wärtsilä inbound stock

Supplier A					
ENGINE CONFIGURATION	W12V32 (D/DF)	W16-18V32 (also 16	12-20V32, 34SG, PP	6-7L32, 6L34	8L-9L32, 9L34
TOG	32	32	45	30	43
in %	100%	100%	100%	100%	100%
TOY	25	25	35	23	34
in %	78%	78%	78%	78%	78%
TOR	11	11	15	10	15
in %	35%	34%	33%	35%	35%

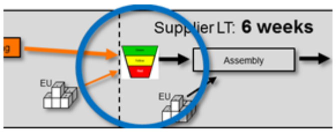


Supplier B						
ENGINE CONFIGURATION	8-9L32 2-STAGE	6-7L32 2-STAGE	W18-20V32 2-stage	18-20V32 PP D-desi	8/9L32E 2-stage	6L32E 2-stage
TOG	45	39	102	57	39	47
in %	100%	100%	100%	100%	100%	100%
TOY	38	33	86	48	34	39
in %	83%	83%	84%	84%	87%	82%
TOR	12	11	30	17	8	11
in %	27%	27%	29%	30%	21%	23%

Supplier C											
ENGINE CONFIGURATION	6-7L32 1-STAG	W12V3E 2-sta	W12V32 C, D 2	W12V3E 1-sta	W6L+9L34SG+	W12V32 C,D 1	18-20V32 PP D	6L32E 2-stage	8/9L32E 2-stag	16V32E 1-stag	8/9L32E 1-stag
TOG	53	55	49	39	45	76	52	36	32	25	24
in %	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
TOY	46	48	43	34	39	65	45	31	28	22	21
in %	86%	87%	87%	87%	87%	86%	87%	86%	86%	86%	86%
TOR	10	12	11	8	9	11	11	7	6	4	4
in %	19%	21%	22%	21%	20%	14%	20%	19%	18%	14%	18%

APPENDIX 6: Replenishment buffer zones for case 2 replenishment buffer in supplier intermediate stock

Component	End cover 1	End cover 2	End cover	End cover 4
TOG	84	76	81	65
in %	100%	100%	100%	100%
TOY	64	56	61	45
in %	76%	74%	75%	69%
TOR	32	31	31	27
in %	38%	41%	38%	41%



Component	Reverse cover 1	Reverse cover 2	Reverse cover 3
TOG	57	46	27
in %	100%	100%	100%
TOY	48	38	22
in %	83%	83%	82%
TOR	15	12	6
in %	27%	26%	24%

Component	Special casted part
TOG	45
in %	100%
TOY	39
in %	87%
TOR	9
in %	21%

Component	Special bolts
TOG	364
in %	100%
TOY	292
in %	80%
TOR	112
in %	31%

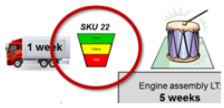
Component	Side plate 1	Side plates 2-5
TOG	62	205
in %	100%	100%
TOY	48	160
in %	78%	78%
TOR	21	71
in %	34%	35%

Component	Tubes 1	Tubes 2
TOG	22439	54027
in %	100%	100%
TOY	17602	42317
in %	78%	78%
TOR	7928	18898
in %	35%	35%

Component	Air by pass sealing 1
TOG	142
in %	100%
TOY	107
in %	75%
TOR	57
in %	40%

APPENDIX 7: Buffer zones for case 3 replenishment buffer in Wärtsilä inbound stock

ENGINE CONFIGURATION	12V32	12V32	12V32E	12V32E	16V32	16V32	16V32	20V32	20V32E	20V32E
SUPPLIER	A	B	C	B	C	A	B	A	C	B
TOG	95	58	36	30	79	70	70	41	59	103
in %	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
TOY	82	47	28	22	62	60	56	30	46	84
in %	86%	81%	78%	72%	78%	86%	81%	75%	79%	81%
TOR	14	15	11	11	24	13	18	13	19	29
in %	14%	26%	29%	38%	30%	18%	26%	33%	32%	28%



ENGINE CONFIGURATION	6L32	6L32E	6L32E	8L32	8L32	8L32E	8L32E	8L32E	9L32	9L32	9L32E	9L32E	9L32E
SUPPLIER	B + C	C	A	A	B + C	C	A	B	A	B + C	C	A	B
TOG	76	26	143	48	66	26	48	28	84	57	53	48	77
in %	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
TOY	60	20	122	41	52	20	41	21	73	46	40	41	62
in %	79%	76%	86%	86%	79%	76%	86%	72%	87%	80%	76%	86%	81%
TOR	26	6	20	7	21	6	7	11	16	20	12	7	22
in %	34%	24%	14%	14%	32%	24%	14%	38%	19%	35%	24%	14%	28%