

## MASTER

### Determination of material requirement changes of a demand proposition before an MRP run a case study at Philips Healthcare MR

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*Determination of material  
requirement changes of a  
demand proposition  
before an MRP run*

*A case study at Philips Healthcare MR*

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## **Abstract**

In this report we propose a mathematical model to calculate material requirement changes that a proposed demand plan introduce. The method was developed to assist a feasibility check of a proposed demand plan, before entering the demand plan in the MRP system. A demand plan should be feasible when entered in an MRP system to avoid rescheduling, which cause nervousness in the MRP system. The mathematical model is based on basic MRP logic so that it can be implemented easily in manufacturing environments that use MRP systems. The research found that in addition to basic MRP logic, a configuration percentage is essential to calculate correct material requirements. The configuration percentage describes the probability that optional components, and the materials that go into the optional components, will be included in future sales. The research and proposed mathematical model solve a common business problem for the high-tech industry where complex BOM structures are the norm, which causes employees being unable to determine if a change in a demand plan will introduce a heavy impact on the supply chain in terms of material requirements.

## Management summary

The standard business information system used by manufacturing firms is MRP. MRP is an accounting program that in particular assists the operational processes of a firm. One task the MRP system performs is calculating the material requirements, based on up-to-date demand data and a Bill-Of-Materials (BOM). However, production- and supplier lead times are often longer than sales lead times. This means that actual demand data is not available when materials need to be ordered. Instead manufacturers use sales forecast data to drive material procurement. In the high-tech industry the manufacturing processes and required materials can become increasingly complex, resulting in complex BOM structures. Such complex BOM structures leave employees with little knowledge about the impact a change in sales demand has on material requirements. In the high-tech industry the production and required materials are capital intensive. Keeping the correct inventory levels is a key financial factor.

When a new forecasted demand plan is released, management wants to check if the demand plan is feasible. Normally a proposed demand plan is released and a feasibility check is performed by all relevant departments. Material requirement and material requirement changes form a crucial part of the feasibility of a demand plan. When a demand proposition will introduce large changes to the material requirements of a manufacturer, the manufacturer has to first check if these material requirements changes can be met by its suppliers. Because BOM structures can be very complex in the high-tech industry, the feasibility of a proposed demand plan in terms of material requirements can only be assessed when demand data is entered in an MRP system and an MRP run is performed. However, manufacturers cannot enter forecasted demand data in their MRP system because it can either be infeasible or tends to change significantly over time, which both requires the demand data in the MRP system to be updated frequently to see what the new material requirements are, causing nervousness in the MRP system, which is not desired (Carlson, et al., 1979).

In this research a method is proposed to calculate the material requirements and material requirement changes of a proposed demand plan, without altering the manufacturers MRP system. The method is based on MRP logic but does not require the demand plan to be entered in the MRP system of the manufacturing, avoiding nervousness in the MRP system. The research is conducted at Philips Healthcare MR, where MRI devices are manufactured, which are used globally to diagnose patient illnesses. Philips Healthcare MR uses an MRP system to drive operations, and the BOM structures of MRI devices are considered highly complex.

The research investigates the current process implemented by Philips Healthcare MR to obtain material requirements from a demand plan and consequences of the method used. In this process aspects are identified that are essential in calculating the material requirements, which are the following.

- BOM structures
- Demand data
- Configuration percentage

The demand data and BOM structures are standard MRP components, and the configuration percentage is not a standard MRP component. The configuration percentage gives the probability an optional component is included in future sales, based on historical averages and known customer

orders. It is important when calculating the correct material requirement for materials that are used in the optional components. The method used shows consequences that relate to forecast accuracy of the proposed demand plan or managerial issues. Based on the essential aspects a mathematical model is proposed that calculates the material requirements. The model allows for two different demand situations as input to calculate the changes between the demand situations, which were considered important to check the feasibility of the new demand situation, in terms of material requirements, with suppliers. The method proposed is a simple mathematical model that can be easily implemented in a business environment with spreadsheet software. The research concludes with studying the proposed method, in the form of a tool programmed with VBA, in the case environment at Philips Healthcare MR. The case study shows that the proposed method is perceived to be valuable by employees, and provides employees a handle to perform a feasibility check of a proposed demand plan, in terms of material requirement.

Because the method uses the same input data as an MRP system it is suitable for implementation in environments where MRP systems are used. This makes it a wide spread solution to implement since MRP systems are used globally by manufacturing firms. High-tech manufacturers are likely to encounter the same business problem when a demand plan is proposed. Therefore we recommend implementing the proposed method in high-tech manufacturing environments to improve the anticipation on material requirement changes.

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### III List of Abbreviations

ABC	Activity-Based Costing
BMS	Business Management System
BOM	Bill-Of-Materials
BPMN	Business Process Model and Notation
IS	Imaging Systems
K	Kelvin
MPS	Master Production Schedule
MR	Magnetic Resonance
MRP	Material Requirements Planning
MRP-II	Material Resource Planning
MTO	Make-to-order
NC	Numerical Code
OIT	Order-in-take
OOS	Out-of-stock
POR	Planned Order Releases
PTS	Pick-to-stock
S&OP	Sales & Operations Planning
SAP	Systems Applications and Products <i>officially in German: Systeme, Anwendungen und Produkte</i>
SKU	Stock-Keeping-Unit
SMI	Supplier Managed Inventory
SMOI	Supplier Managed and Owned Inventory
T	Tesla
VBA	Visual Basic for Applications
VMI	Vendor Managed Inventory

# 1. Introduction

In this master thesis the use of basic Material Requirements Planning (MRP) logic before an MRP run is evaluated to provide insight on material requirement and material requirement changes that assist in assessing the feasibility of a proposed demand plan at Philips Healthcare MR. An MRP run is the recalculation of the entire MRP system. This is normally performed when new data is entered into the MRP system, or changes are made to existing data in the system. This is normally scheduled on set times when the MRP system will be less used. A proposed demand plan is an overview that states the forecasted demand of finished goods, i.e. products that are sold to the customer. An example of a demand plan is depicted in Table 1. In the table the expected quantities of sales for finished good X, Y, and Z are shown per month, per quarter, and in total.

Table 1 - Demand plan example

Product	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Tot	Q1	Q2	Q3	Q4
X	3	2	3	2	2	1	1	2	3	3	1	4	27	8	5	6	8
Y	2	3	2	3	2	3	2	2	3	2	0	4	28	7	8	7	6
Z	3	2	1	1	4	2	3	3	1	3	4	1	28	6	7	7	8
Total	8	7	6	6	8	6	6	7	7	8	5	9	83	21	20	20	22

Philips Healthcare MR sells medical equipment that uses Magnetic Resonance (MR) technology. The most prominent examples are MRI devices, which are widely used around the world to diagnose patient illnesses. A detailed company description will be provided in Chapter 3. The devices sold by Philips Healthcare MR are capital intensive goods. Capital goods are “machines or products that are used by manufacturers to produce their finished goods or that are used by service organizations to deliver their services” (Kranenburg & Van Houtum, 2014). Such finished goods are normally relatively expensive and remain in use for multiple years. The production and required materials for MRI devices are capital intensive, which have a combined value that is relatively high. Having the correct inventory is a key financial factor.

An MRP system is an elaborated accounting program that assists multiple aspects of a firm, and in particular the operational side that is relevant for this research. Material requirements are normally computed by an MRP system. Material requirements indicate what quantities of specific materials are required in order to manufacture all finished goods. An MRP system requires actual demand data and a BOM to calculate the correct material requirements. However, because production- and supplier lead times are often much longer than sales lead times the actual sales data is often not available when materials need to be ordered. Instead sales forecasts are used to provide data for the ordering process. In general, sales forecasts are updated every scheduling period, fluctuating in demand. These fluctuations result in changed material requirements between scheduling periods. For the procurement of materials the material requirements are important when determining the correct material orders. Incorrect orders can lead to increased inventory, obsolete inventory, or Out-Of-Stock (OOS) situations. The products manufactured by Philips Healthcare MR are high-tech, which often have complex manufacturing procedures and include numerous materials. For a complex product it is difficult to determine what materials are required to meet the forecasted sales demand without an MRP run calculating the material requirements. However, if the material requirements for the forecasted sales demand cannot be met by the suppliers, the forecasted sales demand should

not be entered into the MRP system to avoid that infeasible demand data is spread through the whole MRP system. Infeasible demand plans leads to rescheduling the demand. Rescheduling too often introduces system nervousness, which is undesirable (Carlson, et al., 1979). The material requirement changes that a forecasted demand plan introduce should be known before an MRP run, in order to assist in assessing the forecasted demand plan on its feasibility. The changes in material requirements are good indicators to what degree the procurement plan of materials requires change.

This thesis aims to propose a method to assist in anticipating on material quantity requirements based on changing finished good demand forecasts for complex finished goods. Philips Healthcare MR will be used as a case environment, which resembles a high-tech manufacturing industry. The outline of this thesis is as following. Before a proposition on a solution for the mentioned business problem can be made, one should first have a general understanding of the concept of MRP and its place in the supply chain. This information will be provided in chapter 2. In chapter 3, a detailed description of the problem and the company that provides a case environment for the research is given. Chapter 4 provides the research questions that guide the research. Chapter 5 evaluates the framework to execute the research. Chapter 6 and 7 cover the first part of the research, which is descriptive. Chapter 8 covers the second part of the research, here a method to solve the research problem is proposed. The third part of the research is covered by chapter 9 where the proposed method is evaluated on its perceived value. The research concludes with the research conclusions and recommendations in chapter 10.

## 2. Literature

This chapter will introduce the topics of the research. Section 2.1 introduces the concept of MRP, Section 2.2 explains why an improvement to an MRP system is desirable, and in section 2.3 MRP is elaborated in more details. Section 2.4 covers the shortcomings of current MRP systems, and 2.5 evaluates the Sales & Operations Planning, which concludes the vital literature relevant for the scope of this research.

### 2.1 MRP concept

MRP is a business information system that operates as a scheduling package. It originates from IBM in 1960's and has grown towards the standard in the industry for production control (Mohan & Ritzman, 1998). After MRP came to existence, it has undergone many transformations and add-ons to adjust for specific as well as broader contexts. MRP lays the foundation for Manufacturing Resources Planning (MRP-II), Business Resources Planning (BRP), Enterprise Resources Planning (ERP) and Supply Chain Management (SCM). These systems are the best known offspring of the original MRP (Andrei, 2015).

Minty et al. (1998) stated that:

*"The techniques developed in MRP to provide valid production schedules proved so successful that organizations became aware that with valid schedules other resources could be better planned and controlled"*.

This awareness led to the further development of MRP into Material Resource Planning (MRP-II) in 1980. MRP-II was not a replacement or improvement of MRP but rather an expansion of the scope of the system. MRP-II has been the most predominant system for manufacturing control (Toomey, 1996). When spoken of MRP in this era, there is made no distinction between MRP and MRP-II. In essence the original MRP module is still the same in MRP-II, with the addition of extra modules to better fit manufacturer's needs.

MRP is a logic that provides the structure for production planning and inventory control systems. A system with such logic integrates data from production schedules, inventory, and BOM's in order to calculate purchasing and shipping schedules of all materials that are required to manufacture a product. An MRP system has three primary functions (Orlicky, 1973).

First, it ensures that the correct materials are available for production and the necessary finished goods are available in time for customers to acquire. This helps to reduce down-time due to material unavailability. In addition it helps to determine the amount of finished goods that are available for shipping to customers and by what date, reducing the chance of not being able to meet customer demand. If customer demand is not met as promised, customers may switch to a new supplier entirely or will ask for substantial discounts with future shipments. Both cases have a large negative impact on manufacturing companies and are ought to be avoided.

Second, an MRP system helps to reduce waste by presenting the lowest levels of stock possible of all materials and finished goods to keep operations functional. It allows manufacturers to plan and schedule production in such a manner that little or no excessive inventory is required. This is important for manufacturers to preserve capital and to have an effective use of working capital.

Having less excessive inventory on hand leads to less valuable money being tied up in inventory. Tied up funds remain tied up until the finished goods are sold and paid by customers. Tied up funds do not directly form risks for companies, while indirectly it slows down development progress and decreases flexibility for sudden demand changes. With standard payment terms of 90 to 180 days, such situations should be avoided. Also, not having to allocate warehouse capacity for excessive inventory, manufacturers are able to save on storage costs. Business capital is more useful if it remains more liquid, so that it can be used for other funds.

Third, an MRP system assists in the manufacturing planning functions, delivery schedules, and purchasing orders. Because of its clarity of information about quantities of finished goods and their respective completion dates, manufacturers can better schedule sales. Such information adds to a higher purchasing efficiency and more controlled delivery scheduling. This is increasingly important for manufactures with operations spread out over several countries as they can improve the on-time shipment significantly. If an MRP system is working properly, it reduces material waste to a minimum without out-of-stock or shortage situations.

## **2.2 The need for improvement**

In the era where the competition between manufacturing companies has become a global game, ensuring that business operations are performed as efficient as possible is crucial to obtain an economic advantage. The dynamic and changing aspects of global manufacturing, a global market, various logistics such as 'just-in-time', and ever ongoing cost reduction are the norm of today. These types of logistics have found their way into most departments of a firm, including marketing, sales, purchasing, manufacturing, distribution, and services. Some decades ago, manufacturing companies were only competing with other local businesses. Today they are competing with manufacturers around the globe, both large and small. Companies and their manufacturing managers must welcome every opportunity to increase the competitive edge (McKay, 1993). To ensure business operations are performed as effective as possible, the majority of the manufacturers focus on supply chain optimization. A large part of such optimizations depends on implementing good information technologies in order to improve operations planning, inventory controlling, and logistics. This creates pressure to cut lead times and inventories, while maintaining or even increasing quality and product variety. Traditionally supply chain optimization is focused around two aspects: the inventory and the information (Pfohl & Gomm, 2009; Wutke, et al., 2013).

Current developments on effective supply chain management require high levels of information and communication technologies (ICT) as enablers. A large proportion of knowledge in supply chain management rests on the availability of information and methods to analyze the information into useful results (Simchi-Levi, et al., 2000). Supply chain management incorporates multiple functional areas within companies and largely depends on the communications between these areas. For this reason, information technologies can be used as a strong competitive advantage by many companies. Especially large retailers, transportation, airways, or large manufacturing industries have started to widely introduce information technologies. MRP is a system that functions as an elaborated accounting program that aids in the operational process of a company. To be able to release money that got 'stuck' in the supply chain, a good business information system can have a huge impact. McKinsey & Company (2008) discuss that financial volatility within a supply chain is in the top three of priorities of supply chain managers during the period 2007-2010 and remains in the top priorities until 2015.

### 2.3 MRP logic

In this section the logic and working method of MRP are evaluated. The section begins with the input requirements, continues with the calculation logic of MRP, and concludes with the outputs.

MRP is designed to answer the following three questions.

*“What is needed? How much is needed? And When is it needed? (Hopp & Spearman, 2000)”*.

The logic of MRP is designed to be able to manage a manufacturing environment, especially when a large set of SKUs (Stock-Keeping-Units) are produced, large amounts of materials are involved, or many different suppliers are used. Even though it was designed to comprehend large quantities of data, the system performs equally well with smaller amounts of data. MRP works backwards from a production schedule of finished goods to obtain a requirements list of all (raw) materials. Before an MRP system can be implemented, the required input data should be available. The input data consists of:

- Master Production Schedule
- Bill-of-Material
- Inventory Records

These information sources should have a high level of accuracy and integrity. The three input data will now be elaborated.

- *Master Production Schedule (MPS)*: is a schedule that is developed from firm orders or from demand forecasts. The MPS specifies what quantity of each finished good needs to be produced and what their due dates are within each planning period. The MPS is one of the three key inputs that allow an MRP system to calculate detailed timings for component manufacturing and material procurement. It is a summary of what the manufacturer plans to make and drives the operations in terms of what needs to be assembled, made, and bought. In addition it lays a basis for planning the work floor and equipment, and determines the requirements for materials and cash (Law, 2009). Table 2 provides an example of a MPS. The MPS aims to schedule net requirements as stable as possible, while maintaining low inventory levels. This reduces fluctuations in the supply chain.

Table 2 - MPS example

Master Production Schedule	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand	100	110	90	90	80	60	100	120	100	110	90	70
Inventory	30	20	0	0	0	10	40	30	10	10	0	0
Net Requirements (MPS)	90	90	90	90	90	90	90	100	100	100	90	80
Balance	20	0	0	0	10	40	30	10	10	0	0	10

- *Bill-of-Materials*: MRP makes use of BOM explosion to produce accurate demand needs for all sub-assemblies and (raw) materials that are required for a finished good. The BOM is a predefined structure that holds relational information between materials. It works with different levels, where each level corresponds to a set of materials or sub-assemblies that are required to manufacture the assembly in the level above. Figure 1 depicts a fictitious example of a BOM structure.



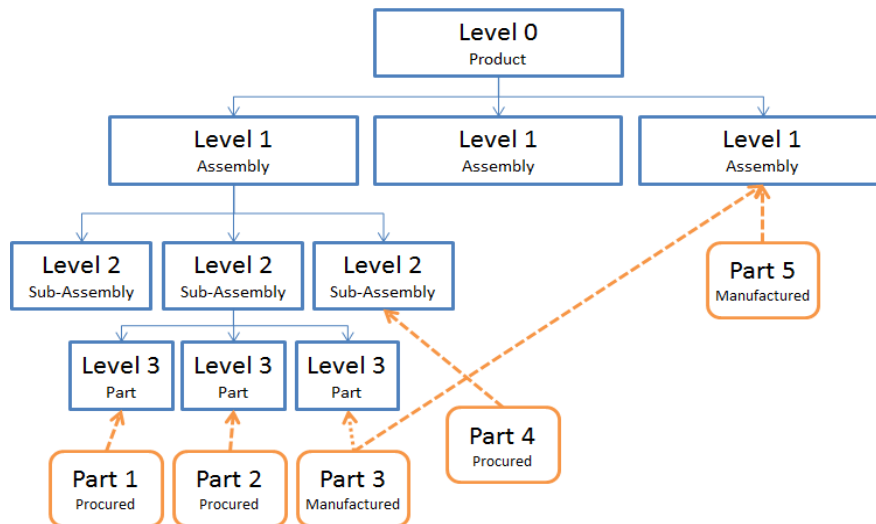


Figure 1 - BOM structure

Within each sub-assembly all the required materials or sub-assemblies are defined, including the required quantity of each material and its production time. With the use of the BOM an MRP system can generate an overview that resembles the total material capacity requirements to fulfill all product demand. This overview serves as initial input data for other organizational functions such as material procurement. With complex finished goods, the BOM structure can be a very complex structure that involves many relations between materials and sub-assemblies.

- *Inventory Records*: in addition to the BOM structure, an MRP system needs information about each specific material and sub-assembly that is used in the manufacturing environment. The inventory records provide an accounting of how much inventory is on hand or on order, and thus should be subtracted from the material capacity requirements. The inventory records file is used to track information on the status of each material by time period. This includes gross requirements, scheduled receipts, and the expected amount on hand. It also includes other information such as supplier, the lead time, and lot sizing information.

Throughout MRP, the system uses two dimensions that are leading in its information sources. The two dimensions are quantities and material identification. These dimensions form the basis in every piece of information. The system begins with scheduling the required finished goods, i.e. demand. The finished goods are scheduled by due-date through the MPS. The next step is to explode the BOM file one level down for each individual product in relation to their due dates. With this step the material requirements of raw materials and sub-assemblies are calculated and represent the quantities that are needed to produce all sub-assemblies of a product one BOM level down. After the BOM explosion, a comparison of the requirements with the on-hand inventory is performed to calculate the actual demand for operations, which is called *netting*. After this the MRP system will determine the right *lot-sizing* and lead time offsetting (*Time-phasing*) to ensure operations are initiated in time to meet with the demand. This signifies the end of the first iteration. After the first iteration the MRP system will continue an *iterative* process until all BOM levels are exploded and the complete material requirements are calculated with the corresponding due-dates. This process can be summarized in the following bullet points:

- *BOM explosion*: Combine the start date, BOM and lot sizes to determine the requirement of the sub materials that are 1 level down.
- *Netting*: Determine the net required materials by subtracting the on-hand inventory. The total finished goods quantity required is determined. All lower level materials demand is generated in next MRP iterations.
- *Lot sizing*: Divide net demand into lot sizes for jobs.
- *Time phasing*: Offset the job due dates with the known lead times. This will generate starting times for the jobs.
- *Iterate*: Repeat all steps until all levels of sub materials have been processed.

In figure 2 a schematic overview is given of a standard MRP system to illustrate the general explanation of its logic.

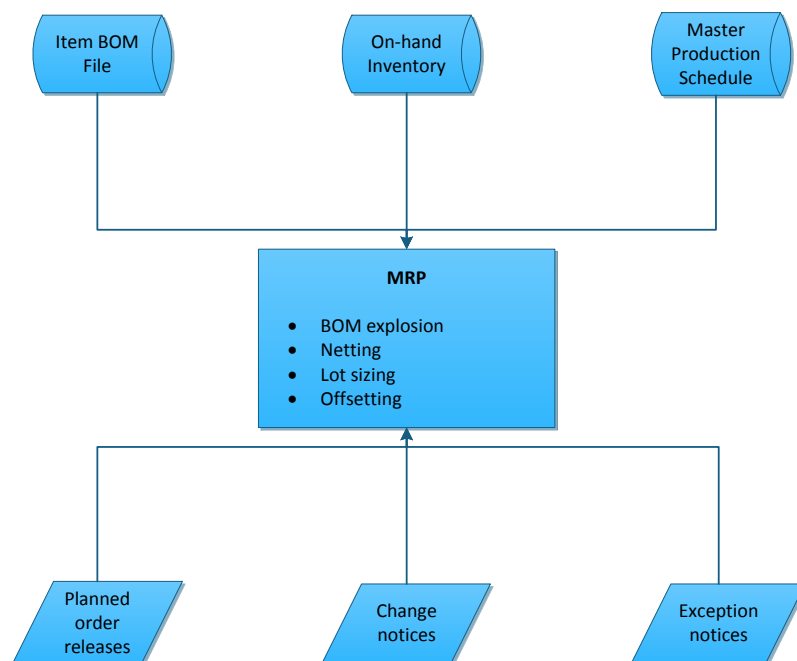


Figure 2 - MRP basic logic

As presented in figure 2, the outputs of an MRP system are Planned Order Releases (POR), Change notices, and Exception notices. The outputs initiate the operational part of a company, such as production, procurement, and other logistical processes. The outputs are now briefly elaborated.

- *Planned order releases* generate the first input for the operational part of a company. They described what needs to be ready, when it needs to be ready, and when production of it should start. The planned order releases are based on production times, material availability, and the calculated requirements of sub-assemblies and/or finished goods.
- *Change notices* hold information about alterations to standing POR, such that demand is met in the most efficient way possible. For example, some orders need to be moved to the front to meet changed delivery data.
- *Exception notices* hold information about operational exceptions, due to some case specific circumstances. For example, finished goods that require a different production path than normal, or are required earlier then presumed to be possible by the system.

The primary function of MRP is calculating material requirements based on a demand input. For example when calculating the material requirements for the manufacturing of an MRI device the following BOM structure is used:

- Finished good: 1 MRI device
- BOM level 1
  - Magnet x 1 per MRI device
  - Amplifier x 2 per MRI device
- BOM level 2
  - Gradient Coil x 1 per Magnet
  - Amplifier Coil x 3 Amplifier

Table 3 provides demand for table’s per time interval and calculates the correct material requirements for each time interval with the table BOM structure through MRP logic.

**Table 3 - MRP primary calculation example**

Product	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MRI Device	5	5	5	4	3	3	3	2	4	5	6	5

Material (level)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Magnet (1)	5	5	5	4	3	3	3	2	4	5	6	5
Amplifier (1)	10	10	10	8	6	6	6	4	8	10	12	10
Gradient Coil (2)	5	5	5	4	3	3	3	2	4	5	6	5
Amplifier Coil (2)	30	30	30	24	18	18	18	12	24	30	36	30

**2.4 MRP shortcomings**

Although MRP is a large step forward in manufacturing environments to increase operational efficiency and reduce inventory and waste, it is not complete. The input of MRP systems depends on manufacturing variables, without taking into account uncertainties in variation in lead times, machine breakdowns or unavailability of materials and operators (Koh, et al., 2002). By not taking into account all these aspects, MRP has some shortcomings.

- *Capacity infeasibility:* the MRP working method is a production line with fixed lead times. The fixed lead time is independent of the amount of work in the plant, which creates the assumption that there will always be sufficient capacity (McNair & Vangermeersch, 1998). Because of this an MRP environment can easily overstate a MPS. An overstated Master Production Schedule means that the demand cannot be met on time. As a result from this, the raw materials and WIP inventories increase in an attempt to cope with the due-dates. More materials are bought and released on the work floor than can be completed or shipped out, which is a secondary result and translates to work on the floor building up and queues to form. Now jobs have to wait before they can be processed which leads to increased lead times and increased missing shipping dates.
- *System nervousness:* system nervousness occurs when a (small) change is made to the MPS that results in a large change in the POR. To maintain a stable MPS is a difficulty for most companies, mostly due to changing customer requirements, supplier and production problems, and changes in sales forecast. It is especially the case when customer service is an

important factor. In organizations where frequent adjustments to the MPS happen the whole MRP systems becomes very nervous. The nervousness can lead to major changes for the production plant and its suppliers. Such nervous systems have increased production and inventory costs (Steele, 1976). Since early planned order releases are the ones in which changes are most disruptive, a frozen zone, an initial number of periods in the MPS in which changes are not permitted, can dramatically reduce the problems caused by nervousness.

- *Requirement analysis:* MRP systems do not have the capability to allow actual material requirements to be determined before lot sizes are determined. This can only be determined during an MRP run, which is often performed once every planning cycle, where planning cycles tend to be on a monthly basis to avoid too much (little) fluctuations in material demand. For operations, this means that the MRP system cannot determine what is exactly required until the manufacturer receives an order that explicitly specifies the unique combination of the finished goods demanded (Cheng, 1997). This can be difficult to cope with for manufacturers with complex production processes and logistics. For this reason it is common that material planners use dummy-orders in the system to reduce inaccuracy and heavy fluctuations due to forecasting. With the inability to determine if the available material requirements are can be met before lot sizing, manufacturers face a difficulty in addressing order requests. Manufacturers are not able to judge if orders can be handled with respect to the requested due-date (Andrei, 2015).
- *Bill-of-Materials:* the BOM file is subject to inaccuracy which is a common source of problems in MRP environments. The BOM can change rapidly, especially in high-tech companies, due to design changes. An inaccurate BOM means that the material requirements that are generated with an MRP system are inaccurate. This type of problem is more common to happen at companies that produce finished goods with a complex BOM structure (Correll, 1995). When complex BOM structures are used, the amount of relations between materials and sub-assemblies are too numerous for operations to keep track off. When BOM complexity is high, employees can have a hard time identifying what the demand of finished goods means for material requirements changes.

## 2.5 Sales & Operations Planning

Where MRP was developed to increase the performance, Sales and operations planning (S&OP) strives to synchronize the supply chain (Klugman, 2014). S&OP is an integrated business management process. S&OP is defined as:

*"function of setting the overall level of manufacturing output (production plan) and other activities to best satisfy the current planned levels of sales (sales plan and/or forecasts), while meeting general business objectives of profitability, productivity, competitive customer lead times, etc., as expressed in the overall business plan (Cox & Blackstone, 2005)".*

A primary task of S&OP is to determine production quantities that assist in maintaining, raising, or lowering material requirements and workforce. The adjustment process has the focus on what the changes are between the previously agreed sales and operations plan and the current state of sales and the supply chain. Such a plan affects multiple organizational functions. The determination of production quantities is a direct input for the MPS that is previously discussed.

The S&OP is often prepared with information from marketing, manufacturing, engineering, finance, and materials. The planning frequency and its planning horizon are dependent on the industry. Short horizons are often used when there are short product life cycles and high demand volatility where longer horizons are used with steadily consumed goods. If performed correctly the S&OP positively influences the supply chain management.

### 3. Problem statement

This chapter will evaluate the possibilities and challenges of the research. Where in the previous chapter the problem context from a literature standpoint is described, this chapter focuses on the problem definition. First, the general problem as proposed by the literature is evaluated in section 3.1. Section 3.2 elaborates on current solutions found in the literature. Section 3.3 provides a short case description and section 3.4 elaborates on the case environment more extensively. The chapter concludes with the problem statement that is the driver of the research.

#### 3.1 Problem description

The philosophy of MRP and its logic is a broadly used concept for manufacturing environments. It assists in calculating material requirements for finished good demand and other operational requirements, while preventing heavy fluctuations in the supply chain. The system asks for an accurate finished goods demand plan from the S&OP, product structures (BOM), and inventory information including lead times and routing times. However, the MRP system has a shortcoming that leads to an operational problem.

The output that an MRP system generates is only accessible after an MRP run. An MRP run means that the system calculates all iterations of the BOM as explained in chapter 2. This is normally performed in weekends when the system is less in use by employees to retrieve data. MRP systems require a MPS as its primary input to base calculations on, thus the MPS needs to be available before an MRP run with accurate up-to-date demand information. The problem with this workflow is that an MRP run alters the information within the system such as available materials, which leads to the possible conclusion that the suggested MPS is infeasible. The MPS resembles the demand plan. Having an infeasible demand plan has consequences to the whole integrated supply chain from supplier to production floors (Orlicky, 1973). As a result the MPS and MRP are often updated to match the feasibility of the demand.

For example, if a finished goods due date cannot be met it is moved backward in time, or when a customer demand is urgent it is moved forward in time. When updating too often the MRP system becomes nervous, this is difficult for suppliers and production operations to follow. Updating it not often enough results in inaccurate data for operations (Blackburn, et al., 1985).

Either way, the operational efficiency is reduced (Carlson, et al., 1979). The manufacturers are left with a loop in the MRP system they cannot escape: to know if a demand plan is feasible it has to be calculated by the MRP system, but a demand plan should only be used as input when it is feasible to prevent system nervousness that leads to operational inefficiency.

When assessing a proposed demand plan, the stakeholders are asked to provide feedback on its feasibility. When providing feedback that is based on material requirements, the BOM structure is the only source that holds this information. BOM structures can be very complex and consist of many layers as described in section 2.3. It is difficult for stakeholders to provide feedback on the feasibility of material requirements with a complex BOM. The only way to generate correct material requirement data is to perform an MRP run, which is undesirable. The process of checking if the proposed demand plan is feasible remains a human task. The data generated may provide new logistical insight but it still depends on supplier's flexibility if a proposed demand plan can be met or

not. Because of the importance of supplier flexibility, the quantities of material requirements play a significant role in whether or not a proposed demand plan is feasible. For suppliers it is important to know the quantity, and amount of change in material requirements, per time horizon. This information allows the suppliers to anticipate and adjust production accordingly.

### 3.2 Phenomenon related literature

The phenomenon described is a common problem in the field of manufacturing companies with MRP systems. Most MRP oriented papers discuss alteration or extension to the existing MRP systems. However, we would like to point out that the problem described in this research takes place before an MRP run.

The closest solution found to our knowledge is that of Orlicky (1973). He proposed a net changing method that solves the problem of running an MRP system once a week. The method described is a less heavy calculation that allows the MRP system to be run more frequently to calculate the net changes in material capacity requirements. The disconnection of this solution to the phenomenon described in this research is that the method rests on an up-to-date BOM file and up-to-date demand. The first problems here is that an up-to-date BOM is integrated in an MRP system and with manufacturing environments where changes to the BOM are made rapidly obtaining the correct BOM structures can be difficult. The second more prominent problem is that this method works with real demand data. However, most companies need to assess the proposed demand on its feasibility prior to *netting* it. But in order to assess the feasibility the proposed demand has to be netted. The earlier mentioned loop is still present in this solution.

Another closely related alternative to the phenomenon is that of Clayton (1997), who describes the two widely accepted alternatives to MRP systems. One of the alternatives overlaps Orlicky's (1973) Net-change method and the other consists of a high frequency (or continuous) rescheduling of the MPS. This is at the expense of overall processing efficiency. The latter is valuable when having up-to-date data is highly relevant and manufacturing efficiency is of less importance. For example, for an extremely high-value good industry with long manufacturing times this can be desirable. The problem with this approach is that it can create tremendous amounts of nervousness in the supply chain that is undesirable for efficient production and supply. Continuously re-calculating causes suppliers and shop floor controllers to receive an equally fast changing demand pattern.

Neither of the two alternatives provides a real solution to the phenomenon identified. Both solutions still rest on an MRP run where the desired outcome of this research is to provide a solution before an MRP run to avoid the mentioned loop.

### 3.3 Case description

To study this phenomenon, a case is used that has likewise problems on operational level. Philips Healthcare MR has provided the opportunity to research the phenomenon at its MRI production facility in Best, The Netherlands, where the operational logistics are controlled.

Philips Healthcare MR uses a planning cycle of one month. This means that once a month the S&OP sets up a proposed demand plan. The demand plan is a rolling forecast till end of the year which means that the forecast is adjusted every month based on new information from the sales departments. The proposed demand plan is produced based on market inputs and historical averages. The demand is specified per end product per month. When the proposed demand plan is

released, it has to be reviewed within 2 to 3 working days. All stakeholders are asked to analyze the plan and to provide feedback on any expected difficulties to determine the demand plan's feasibility. The stakeholders include key suppliers, planning, and procurement. Because of the phenomenon previously explained, the current demand plan does not provide any in-depth information on the effects it has on the supply chain in terms of material requirements. The complex BOM structures that are present in MRI devices are normally too difficult to provide material requirement information for given end product without an MRP system calculating them.

The case is relevant because operational issue at Philips Healthcare MR closely resembles the found phenomenon surrounding the use of an MRP system. A proposed demand plan needs to be evaluated on its feasibility within a short period of time, but without running it through the whole MRP system that Philips Healthcare MR is using. The problem is that without an MRP run on the proposed demand plan, its feasibility in terms of material requirements cannot be addressed correctly. In addition, Philips Healthcare MR has a very complex and rapidly changing BOM structure, reducing the ability to judge the impact that demand changes have on material requirements.

Currently Philips Healthcare MR addresses the feasibility of a proposed demand plan with decisions that are based on instinct rather than on qualitative information. This approach can lead to OOS situations due to unforeseen material requirements. OOS situations are solved by employees when the MRP system indicates an OOS will occur, instead of preventing OOS situations to happen. This can be avoided when changes in material requirements are known prior to entering a demand plan in MRP, and performing an MRP run, to anticipate better on OOS situations.

### 3.4 Company background

Philips was founded by Frederik Philips and his son Gerard in 1891. Four years later, Gerard's brother Anton joined Philips. Philips was originally founded to meet the growing demand for light bulbs. Within a few years it was one of the largest light bulbs producers in the world.

Today, Philips has grown into a large diversified technology multinational, selling a variety of technological products. The sales of Philips accumulated to 21.4 billion euro in 2014. It has manufacturing sites and sales and services in over 100 countries. Their headquarters is located in Amsterdam. In January 2013, 115.000 employees were working for Philips worldwide. The mission of Philips is to improve people lives through meaningful innovation. Philips's operates in 3 main sectors, each having their own type of products. The 3 sectors are now briefly discussed.

- **Philips Healthcare** aims to develop innovative solutions to help clinicians diagnose, treat, and manage today's most prevalent diseases as effectively and efficiently as possible. It is a world leader in cardiology and has a strong presence in cardio-pulmonary, oncology, and mammography.
- **Lighting** is dedicated to enhance people's life by developing innovative lightning solutions for customer and industrial markets. Markets served by Philips lightning are homes, office and outdoor, industry, retail, hospitality, entertainment, healthcare, and automotive.
- **Consumer lifestyle** develops technologies such as consumer electronics and small appliances. Examples of products are shaving appliances and coffee machines.

For this research the scope will be at Philips Healthcare and its Magnetic Resonance (MR) division, which will now be briefly discussed.



3.4.1 Philips Healthcare

The headquarters of Philips Healthcare is located in Best, The Netherlands and Andover, Massachusetts, United States. 37.000+ employees are working for Philips Healthcare worldwide. Philips Healthcare sells over 450 products in over 100 countries. The sales over 2012 equaled 10 billion euros, and 8 percent of those sales are invested in research and development.

Philips works with a multi layered business unit model, meaning that each of Philips’s main sectors consist of several separate business intelligence units (BIU) cooperating together and these business units in turn are divided in business intelligence units, going up to 7 layers deep. A compressed organization structure of Philips is depicted in Figure 3.

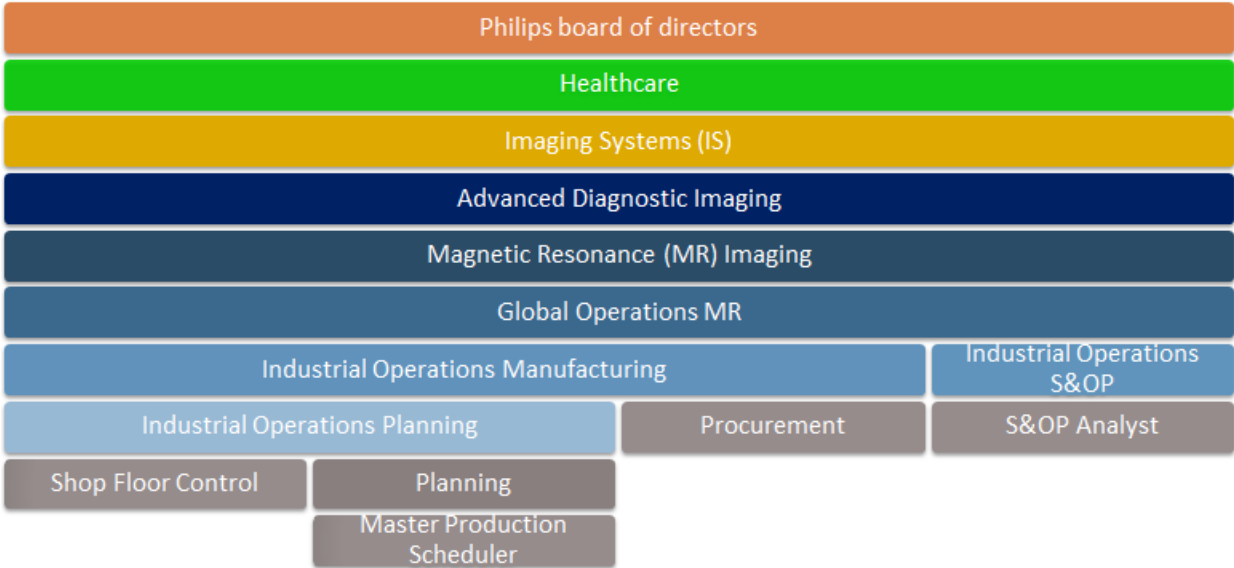


Figure 3 - Company structure

This research will be conducted under the guidance of the Planning and Procurement department of Global Operations MR, which will be referred to as Philips Healthcare MR.

3.4.2 General product description

For this research, the scope will include the product group of Magnetic Resonance Imaging (MRI) devices, which is part of Philips Imaging Systems (IS) department.

- MRI devices:* MRI is a medical imaging technique that is used in radiology to investigate the anatomy and physiology of the body in both health and disease. MRI devices use strong magnetic fields and radio waves to form images of the body. The technique is widely used in hospitals for medical diagnosis, staging of disease, and for follow-up without exposure to ionizing radiation. MRI devices are highly complex with over 1.000 individual parts obtained in a BOM structure. The main materials are the magnet, radio frequency coil and gradient coil. The production of such devices is time consuming due to their precise nature. An MRI device price varies from 300.000 to a 1.000.000 euro, where the biggest cost factor is the size and strength of the magnet used. The magnets offered anno 2015 have a field strength of 1.5 or 3.0 Tesla (T) with a working temperature of 4 or 10 Kelvin (K). Higher field strengths up to 11 T are available but normally only used for scientific research purposes.

- *Device families:* Philips Healthcare MR offers a variety of different MRI devices. These devices are grouped into three families, the Multiva, Achieva, and Ingenia. Each family differs on certain aspects. The main differences between families are the size of the magnets and how expanded the device options are. The size of the magnet allows for more or less room for the patient. Within each family a distinction can be made based on magnet field strength, working temperature of the magnet and number of frequency channels. A brief overview of the devices offered by : Philips Healthcare MR in their catalogue is depicted in figure 4.

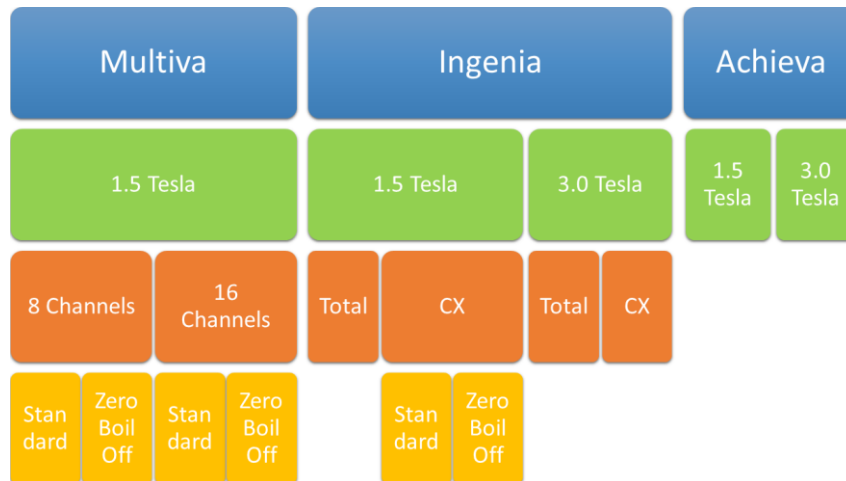


Figure 4 - MRI device types

The explained devices types are referred to as back-ends because of their mechanical nature. The magnet forms the core of an MRI, which comes in 5 different types. A magnet is then surrounded by a package of materials that forms the back-end. In addition to the magnets and back-ends there are also upgrades, which consist of a set of materials that replace or add to an existing magnet and back-end in the field. Because the magnet logistics is controlled separately from the back-ends and upgrades, and the focus of the company problem is with back-ends and upgrades, the magnets are left out of the scope of this research.

### 3.5 Problem statement

Based on the problem context and definition described in the previous parts, the problem stated as follows:

*Philips Healthcare MR experiences difficulties assessing the feasibility of a proposed demand plan in terms of material requirements, with as a result supply chain issues due to unforeseen demand increases.*

In order to gain a valid scientific answer to the problem stated, a research has been designed to provide three complementary steps to address the problems. The first step provides a description of the workflow at Philips Healthcare MR. Evaluating the calculations of the material requirement for a proposed demand plan, with the use of an MRP run. The second step proposes a method that calculates the changes in material requirement of a proposed demand plan compared to a previous demand plan, before an MRP run. The third step focuses on how the solution is perceived to be adequate in a business operational environment to assist in the assessing process of the feasibility of a proposed demand plan prior to entering it into an MRP system.

## 4. Research questions and objectives

In this chapter the research questions and objectives are formulated, based on the problem description and problem statement of the previous chapter.

### 4.1 Research questions

First, the main research question is formulated that functions as the driver for the research project and covers the entire problem context. The main research question of the Master thesis project at Philips Healthcare MR – Best, is formulated as follows:

*How can changes in material requirement be determined before an MRP run, based on a proposed demand plan and an old demand plan, in order to assist in assessing the feasibility of that demand proposition?*

Since this research question cannot be answered at once, it is broken into sub questions. These sub questions are important to define the scope and the boundaries of this Master's thesis project.

#### *Questions Part I*

Firstly, the MRP environment of the case needs to be examined to gain an accurate view on how material requirements are calculated from a demand plan, with the use of an MRP system.

- 1) *How is Philips Healthcare MR calculating material requirements to meet scheduled demand, with the use of an MRP system?*
- 2) *What are the consequences of the methods used in this process?*

The first research question provides a detailed description on the method used to generate material requirement, from a (proposed) demand plan, at Philips Healthcare MR. The second research question evaluates this method and indicates what problems can be identified within this process. The identified problems will not be limited to operations only, rather all encountered problems will be included to provide feedback on managerial level, even if they don't match the scope of the research.

- 3) *Which aspects, used in the Philips Healthcare MR MRP logic, are essential to the generation of correct material requirement data?*

Research question 3 will provide an evaluation of the method described by the first research question and subtract the important aspects that are essential to calculate the material requirements based on a new monthly proposed demand plan of finished goods.

#### *Questions Part II*

This part of the research will propose a method that can be used in operational business environments to solve the problem described in this research.

- 4) *How can the changes in material requirement be calculated, based on a proposed demand plan and a previous demand situation, before an MRP run?*

The proposed method is constructed with information of the case environment of Philips Healthcare MR. The method will be generalized, so it can be applicable across industries.

### *Question Part III*

The third part of the research makes an effort to quantify the contribution the proposed method has on the described business problem.

- 5) *How adequate is the proposed method perceived, in an operational business environment, when assisting the assessing process of the feasibility of a proposed demand plan by stakeholders?*

Research question 5 evaluates the proposed method by analyzing its use in a business setting. The question aims to answer how the solution is perceived to be adequate in a business operational environment to assist in the assessing process of the feasibility of a proposed demand plan prior to input into an MRP system.

## **4.2 Research objectives**

Based on the research questions there are 3 research objectives derived, namely:

- 1) *Provide insight on how material requirements are calculated with the use of an MRP system, at Philips Healthcare MR*
- 2) *Develop a method to calculate material requirement changes that a proposed demand plan may introduce to the supply chain, before an MRP run*
  - a. *The method has to take into account the characteristics of a high-tech manufacturing environment.*
  - b. *The method has to be theoretically funded and generalized to create an academic basis.*
  - c. *The outcomes of the method has to be practically functional*
- 3) *(Optional) Provide a method to improve the ability to filter out important information from the output data of the method, to assist in assessing the feasibility of a proposed demand plan on operational level*

Thereby it is important that this Master's thesis project is conducted according to the regulations and requirements of Eindhoven University of Technology. For example, it is required that the scope of the research project is such that it can be finished within 21 weeks. On the other hand, the objective of the Master's thesis project is to be relevant for Philips Healthcare MR – Best, and to solve the operational problem.

## 5. Research methodology

This chapter will provide an evaluation on how the research questions can be answered. To answer all the research questions the system development life cycle (SDLC) method will be used, also known as the 'Waterfall' methodology (Royce, 1970). The method included 5 successive stages in sequence. The model is perceived to be ideal for a development project (Isaias & Tomayess, 2015). Figure 5 illustrates the methods work flow.

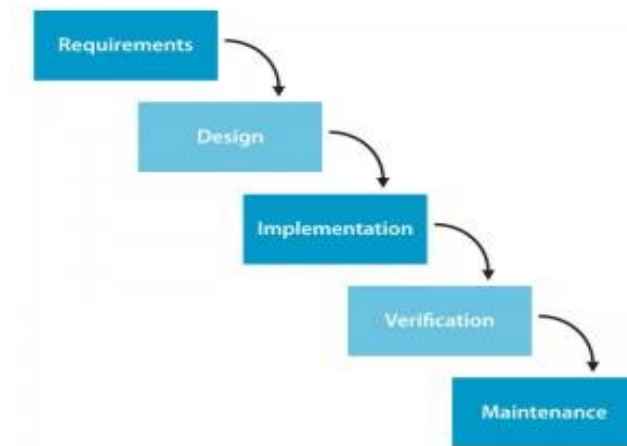


Figure 5 - SDLC 'Waterfall' methodology

The first stage of the methodology will be included in part I of this research, covering research question 1, 2, and 3. The second stage of the methodology will be included in part II of this research, covering research question 4. The last 3 stages of the methodology are included in part III of this research, covering research question 5. Officially, the last stage of the methodology falls outside of the scope of this research, but it will be briefly discussed. Executing the last stage will be entrusted to Philips Healthcare MR employees.

### 5.1 Research methodology part I

This section covers the first part of the research. The function of this part is to extend the theoretical knowledge of an MRP process with practical knowledge of an MRP process in an operational environment. The gained knowledge will provide handles to propose a method as a solution to the described problem of this thesis.

To answer research question 1 and 2 all steps taken by Philips Healthcare MR to get from a proposed demand plan to material requirement are analyzed. All other process steps will be left out. To assist in answering the research questions a descriptive model will be made with Business Process Modeling Notation (BPMN). BPMN is chosen because of its standard with well-defined syntax. Many business users are familiar with it, making collaboration with it much easier. Also most modeling tools support BPMN, making it easy to share and edit (Anon., 2015).

To obtain information about the process at scope, non-standardized open-end interviews will be held with employees. The employees will be chosen based on advice by managers, considering experience

and availability of employees. Interviewing is chosen in order to cover both factual and meaningful information about the process (Kvale, 1996). The interviews have the goal to establish a clear view of the operational process steps that are taken. In addition to the interviews, working sessions will be scheduled to experience the work flow first hand.

To answer research question 3 the current process will be analyzed. The current process is analyzed based on the qualitative process description of research question 1. To underpin the choice of qualitative information; the availability of (historical) data overall is limited, which leads to qualitative interpretation of the case as primary information source.

## **5.2 Research methodology part II**

This section concerns the second part of the research. It covers how a proposition for a solution for the described research problem, and stage 2 of the SDLC cycle (design) is executed.

When a good understanding of the process and essential aspects has been established a method can be designed to solve the research problem of this thesis. The aim is to provide an easy method to solve the problem in business environments. An easy method improves the ability to implement the method, and reduces the level of maintenance of a tool based on the proposed method. To design a method, mathematical modelling will be used. Mathematical modelling is used because software, such as Excel, makes it relatively easy to create a tool based on the equations of a mathematical model. To contribute further to ease of implementation the following structural criteria will be aimed for when modeling.

- A model that exhibits linearity. Non-linearity models normally tend to be more difficult, decreasing the ease of implementation in business environments.
- A model that is static, this allows a system to be calculated in equilibrium (steady-state), which requires no differential equations, reducing its complexity.
- A model that is deterministic, this allows a method in which every set of input is determined by parameters in the model. Therefore, the method should always perform the same way given a set of initial conditions (input).

## **5.3 Research methodology part III**

This section covers the third part of the research where the perceived value of the proposed method is examined in a business operational environment to assist in the assessing process of the feasibility of a proposed demand plan prior to input into an MRP system. Validating the method accurately is a very time consuming task and the validity solely depends on correct programming. Therefore the perceived values of the method as researched.

### **5.3.1 Research design part III**

In order to evaluate the proposed method it has to be tested. A demand plan proposal is released every 3rd week of the month at Philips Healthcare MR. The proposed method will be tested during the feasibility assessing in the months July and August 2015. The stakeholders will be provided with a presentation explaining the use of the method and tool that was developed prior to the start of the assessing.

The method will be tested based on the following propositions through interviews from different perspectives.

- 1) *The proposed method provides the correct material requirement information*
- 2) *The output data variety positively influences the ability to assess the feasibility of a proposed demand plan*
- 3) *The generated output of the proposed method is perceived accurate*
- 4) *The proposed method is perceived to be valid*
- 5) *The proposed method is perceived reliable*
- 6) *The data generated is correctly ordered to assist in the assessing process*

The first propositions try to answer if the method performs the desired calculations to assist in assessing the feasibility of a proposed demand plan. Proposition 3, 4, and 5 try to answer if the method is perceived to be mathematical correct. The 6<sup>th</sup> proposition answers if the output lay-out of the data is desirable and functions as an improvement driver.

### 5.3.2 Employees

The employees at which the interviews were held have been selected based on the following criteria:

- The employee is not deployed on projects or functions outside of MR operations
- The employee has at least 9 S&OP cycles experience of assessing demand plans
- Equal percentile of each gender from the employee pool is asked to be interviewed
- Employees that are selected are stakeholders in the feasibility assessing of material requirements of the proposed demand plan.

An additional criterion that is of importance is the aim to have at least one senior employee who is not a direct user of the method in the sample. It is perceived to be important that the method & tool is also analyzed on its value by a manager who falls outside of the environment it is used for.

### 5.3.3 Interview structure

The approach in the interviews is to trigger the employees to think critically about the proposed method. The sampling method is a case study, which indicates that the provided answers will have very limited generalizability (Blumberg, et al., 2008). The interview technique is 'semi-structured'. The goal of a semi-structured interview according to Blumberg et al. (2008) is explanatory. The aim is to learn the viewpoint of the respondents in regard to the proposed method relevant to the research problem. The interviews are characterized as in-depth interviews with a focus on triggering the interviewees. Focused in-depth interviews are interviews in which the interviewer uses different techniques to offer the interviewee some guidance in answering the questions (Blumberg, et al., 2008). Such type of interviews allows the interviewer to start with questions that are rather specific but simultaneously allow the interviewee to follow his or her own thoughts. After the discussion of each proposition, the interviewee is asked to give a value on a Likert scale regarding the discussed proposition (Likert, 1932).

The Likert scale will have the following format.

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
1	2	3	4	5

Table 4 - Likert scale

### 5.4 Limitations

The magnitude of this thesis is 30 credits which is equivalent with 21 weeks of fulltime work. Time will therefore be a limitation that will affect the scope of this thesis. The research will only focus on developing a solution to provide insight on the material requirements when a proposed demand plan is released, because of the importance this has for manufacturing environments with fast developing technology and often long lead time materials. Other aspects such as lead times, scheduling, and inventory management or buffers will not be evaluated due to the time limitation. However, these topics are possibly good future research topics. The thesis is largely based on a case at Philips Healthcare MR. This will initially lead to an outcome, in the form of a method, which is not directly applicable for other organizations. However, an effort will be made to generalize the result to give a general solution on how to approach a similar problem and, with modifications, be applicable to other instances.



## Part I: Process description & requirements

### 6. Process analysis

This chapter will cover the first part of the research and answers research question 1, 2, and 3. The goal is to provide a detailed description on how Philips Healthcare MR currently translates a proposed demand plan into material requirement data with the use of an MRP system and the surrounding processes. We aim to provide a qualitative description in which two types of aspects can be identified. The first are possible consequences of the process to provide management with feedback for improvement. The second are essential aspects for the development of a solution to the research problem. The complete process at scope will be evaluated in chronological order. The process is triggered by the S&OP department.

#### 6.1 Sales & Operational Planning

One of the primary tasks of the S&OP department is providing a proposed demand plan that forms the basis of all operational actions. With the case at Philips Healthcare MR this plan holds information about what quantities are required per month of each back-end and upgrade in the product catalogue. This plan is released every 3th week of the month with a forecasting horizon till the end of the year. The stake-holding departments are asked to review the new plan and to provide feedback on its feasibility, which is discussed during a meeting where all stakeholders are represented within 5 working days after the proposed plan has been released. The goal of this meeting is to agree with the plan, deny it or agree with possible conditionalities on specific materials. Conditionality means that a specific material might become a bottleneck depending on how the supply chain reacts to the new plan. In table 5 a fictional example of a proposed demand plan was given. Table 5 illustrates a proposed demand plan for back-ends at Philips Healthcare MR with fictional quantities. For upgrades and magnets the setup of a proposed demand plan is equal to that of a back-end plan.

Table 5 - Example proposed demand plan for back-ends

Proposed shipment/slot plan																	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Q1	Q2	Q3	Q4
Leopard Wave 4	1	1	1	1	1	1	1	1	1	1	1	6	17	3	3	3	8
Multiva 1.5T 8 R5	1	4	1	3	3	1	2	1	1	1	2	1	21	6	7	4	4
Multiva 1.5T R5	5	4	6	12	8	6	10	10	8	8	8	5	90	15	26	28	21
Achieva 1.5T Total	11	11	9	16	14	11	14	14	13	14	12	5	144	31	41	41	31
Achieva 1.5T	4	5	2	10	7	5	7	7	7	7	7	2	70	11	22	21	16
Achieva 1.5T R5	7	6	7	6	7	6	7	7	6	7	5	3	74	20	19	20	15
Ingenia 1.5T Total	20	24	23	33	27	26	38	31	30	30	29	20	331	67	86	99	79
Ingenia 1.5T	1	1	1	2	2	2	1	2	2	1	3	1	19	3	6	5	5
Ingenia 1.5T R5	16	17	16	26	20	20	29	23	22	23	21	14	247	49	66	74	58
Ingenia 1.5T S	1	1	1	1	1	1	1	1	1	1	1	1	12	3	3	3	3
Ingenia 1.5T CX	1	3	4	1	1	1	1	1	1	1	1	1	17	8	3	3	3
Ingenia 1.5T CX ZBO	1	2	1	3	3	2	6	4	4	4	3	3	36	4	8	14	10
Achieva TX Total	4	3	3	7	5	4	3	4	5	5	4	3	50	10	16	12	12
Achieva TX	1	1	1	3	2	2	1	2	3	3	3	2	24	3	7	6	8
Achieva TX R5	3	2	2	4	3	2	2	2	2	2	1	1	26	7	9	6	4
Ingenia 3.0T Total	10	16	14	22	22	15	25	19	17	13	9	9	191	40	59	61	31
Ingenia 3.0T	2	1	2	5	4	2	8	3	5	4	2	3	41	5	11	16	9
Ingenia 3.0T R5	7	13	8	14	14	9	14	12	9	5	4	4	113	28	37	35	13
Ingenia 3.0T CX	1	2	4	3	4	4	3	4	3	4	3	2	37	7	11	10	9
Panorama HFO	1	1	1	1	2	1	1	1	1	1	1	1	13	3	4	3	3
<b>Total</b>	<b>53</b>	<b>64</b>	<b>58</b>	<b>95</b>	<b>82</b>	<b>65</b>	<b>94</b>	<b>81</b>	<b>76</b>	<b>73</b>	<b>66</b>	<b>50</b>	<b>857</b>	<b>175</b>	<b>242</b>	<b>251</b>	<b>189</b>
	175		242			251			189								
	20,4%		28,2%			29,3%			22,1%								

The demand is forecasted based on three aspects. First, the order book is consulted on the amount of orders that are confirmed or orders that are not confirmed but have a high potential to be confirmed. Second, the demand data provided by sales agents globally is consulted. Here the S&OP department has to analyze critically to avoid inflated sales leads from agents that might be motivated by their own sales targets. Third, the demand trend of all global markets is calculated. The S&OP department will use these three data sources to generate an as accurate as possible demand forecast as a proposed demand plan.

The proposed demand plan is released, and within 5 working days it is assessed on its feasibility. Assessing the proposed demand plan is done based on its impact on the supply chain. Relevant for this research is the ability to assess the proposed demand plan in terms of material requirement changes.

## 6.2 Master Production Schedule

When the proposed demand plan from the S&OP department is accepted on its feasibility it is released to the planning department. The planning department will process it according to MRP logic. The proposed demand plan is now an actual demand plan. In this paragraph the making of a MPS will be discussed.

### 6.2.1 Demand translation

The proposed demand plan is specified to quantities of each back-end, upgrade, and magnet that are in the product catalogue, as explained in the previous paragraph. The proposed demand plan is time interval is a month, whereas the operational side of Philips Healthcare MR uses a time interval of a day. Philips Healthcare MR uses the MPS to form the link between the monthly demand plan and the operational day plan. Philips Healthcare MR strives to plan the demand over the available working days in a month as evenly as possible, maintain a stable demand pattern throughout.

The method used by Philips Healthcare MR to translate the data from a monthly horizon to daily horizon is as following:

- Keep data per device type
- Divide monthly demand to weekly demand
- Divide weekly demand to daily demand

The approach is rather simple but effective to go from a month to day planning. Table 6 depicts an example of a translation for back-ends for the month June from Philips Healthcare MR. The example is different from the general MPS example given in section 2.3. In MPS example in section 2.3 is defined per month, Philips Healthcare MR constructs its MPR per day. The setup of the table also differs, the time periods are indicates vertically and the quantities are specified per finished good horizontally, identified by a 6 digits code. On the right hand side of the table the column 'Day Qty' resembles the scheduled demand of all finished goods per day, which has to correspond to the total daily manufacturing and shipping capacities of Philips Healthcare MR. The manufacturing and shipping capacity of Philips Healthcare MR is 5 finished goods per day. This amount can fluctuate per day, but has to maintain an average of 5 finished goods per day on monthly basis. The MPS is constructed by manually by employees from the planning department, with the use of a spreadsheet. As a starting point the MPS of the previous cycle is used and changed where needed. When the

translation is complete, the data is can be entered in the MRP system. Once in the MRP system, the scheduled demand can be linked to sales orders.

Table 6 - MPS translation

Date	781072	781073	781078	781262	781271	781278	781296	781341	781342	781343	781345	781350	781377	781396	Day	Day Qty
Delivered	1	4	11	5	8	2	20	81	43	25	8	0	6	2	216	
1-6-2015								1				1	2		MON	4
2-6-2015							1	1			1				TUE	3
3-6-2015				1		1		2	1						WED	5
4-6-2015								2							THU	2
5-6-2015								1	1						FRI	2
8-6-2015		1	1					1	1						MON	4
9-6-2015		1						1	1						TUE	3
10-6-2015		1						1							WED	2
11-6-2015							1	1	1	1					THU	4
12-6-2015								1	1						FRI	2
15-6-2015		1						1					1		MON	3
16-6-2015					1				1	1				1	TUE	4
17-6-2015		1					3								WED	4
18-6-2015							1	1							THU	2
19-6-2015								1		1	1				FRI	3
22-6-2015					1			1	1		1				MON	4
23-6-2015		1					1		1						TUE	3
24-6-2015		1						1	1	1					WED	4
25-6-2015								1	1	1					THU	3
26-6-2015								1	1						FRI	2
29-6-2015								1	1				1		MON	3
30-6-2015								1		1					TUE	2

In some cases, set customer orders introduce inefficiencies to the even distribution of the schedule. In general, it is of importance for the operations of a company to peruse an as stable as possible production and demand pattern to reduce the amount of capacity fluctuations on the supply chain which positively affects production performance and lead times (Feld, 2001). The more capacity requirements fluctuate, the more buffers are required (Selten, 2013). In this case, buffers are in the form of material inventory, sub-assembly inventory, work floor capacity, and inventory of components in a pre-finished state. Pre-finished products in this case are MRI devices that are assembled to modular building blocks, stored in a warehouse ready to be picked for shipment. A complete MRI device is assembled on-site of the customer.

6.2.2 Configuration forecasting

In addition to the monthly to daily translation, the MPS addresses the configurational planning of each product. Products are often offered with a variety of options to choose from. The customers can configure their purchase to their needs. The options create a difficulty in the MPS. Initial scheduled slots in the MPS do not specify the configuration of a product, only which products. These configurations introduce variability in material configurations and the required manufacturing procedures. It as desired to have an estimate on what configurations will be required to reduce the variability. A forecast is made every month using a historical average method. In the case of Philips Healthcare MR a time horizon of 9 months is taken for the historical average. For all materials that are present in level 1 of the BOM the configuration percentages is calculated with the historical average. The configuration percentage indicates to what degree a material is forecasted to be included in an end product. Table 7 shows a selection of optional materials that are used in the configuration of an *Achieva 1.5T* MRI device. The spreadsheet works as following.

- *Historical occurrence*: For each optional component the quantity sold over the last 9 months is indicated (column 6) and expressed as a percentage of the total sold finished goods

(column 7), over the total sold finished goods in which the optional component can occur (5th column).

- *Standing orders*: For the orders already received from customers, the quantity (column 9) and percentages (column 10) are specified in respect to the total orders of finished goods in which the optional component can occur (column 8)
- *Average*: The spreadsheet calculates the average of the historical occurrence and the standing orders (column 12 and 13)

Table 7 - Option calculation

1	2	3	4	5	6	7	8	9	10	11	12	13
C-BoM	12NC	Naam	Geldig tot	Tot.	Qty		Tot.	Qty		Tot.	Qty	
0781-296-102		ACHIEVA 1.5T		39	39	100,0%	39	39	100,0%	78	78	100,0%
0781-296-102	9896-030-00601	COIL POSITION DEVICE	31.12.9999	39	1	2,6%	39	0	0,0%	78	1	1,3%
0781-296-102	9896-030-02203	MICROSCOPY COIL SET 1.5T	31.12.9999	39	1	2,6%	39	0	0,0%	78	1	1,3%
0781-296-102	9896-030-03642	QHC 1H T/R ACS-NT LEFT II	31.12.9999	39	0	0,0%	39	0	0,0%	78	0	0,0%
0781-296-102	9896-030-07462	Achieva Trolley positioning aids	31.12.9999	39	0	0,0%	39	0	0,0%	78	0	0,0%
0781-296-102	9896-030-08212	PAT.OBSERVATION SYS.=>R7	31.12.9999	39	3	7,7%	39	4	10,3%	78	7	9,0%
0781-296-102	9896-030-08225	Trolley	31.12.9999	39	0	0,0%	39	0	0,0%	78	0	0,0%
0781-296-102	9896-030-08391	ACCESSORY CART	31.12.9999	39	0	0,0%	39	0	0,0%	78	0	0,0%
0781-296-102	9896-030-08504	MAGNET ROTATION TOOL NL	31.12.9999	39	0	0,0%	39	0	0,0%	78	0	0,0%
0781-296-102	9896-030-08791	TABLE TOP EXTENDER	31.12.9999	39	6	15,4%	39	5	12,8%	78	11	14,1%
0781-296-102	9896-030-09801	AIR SHIPMENT TOOL	31.12.9999	39	33	84,6%	39	13	33,3%	78	46	59,0%
0781-296-102	9896-030-10661	D.S. PRE-ASSY PT6000 S	31.12.9999	39	2	5,1%	39	3	7,7%	78	5	6,4%
0781-296-102	9896-030-11284	SENSE Head Coil 1.5T 8 Ch	31.12.9999	39	37	94,9%	39	37	94,9%	78	74	94,9%
0781-296-102	9896-030-11603	SENSE Knee Coil 1.5T 8Ch	31.12.9999	39	14	35,9%	39	14	35,9%	78	28	35,9%
0781-296-102	9896-030-11615	SYN. BODY COIL 1.5T ODU	31.12.9999	39	27	69,2%	39	26	66,7%	78	53	67,9%
0781-296-102	9896-030-11654	SYN HEAD/NECK COIL 1.5T O	31.12.9999	39	2	5,1%	39	3	7,7%	78	5	6,4%

Note: both the historical sales over the past 9 months and the standing orders are 39 units, this is coincidence. Normally these values are not equal.

For example, from table 7 it can be concluded that the Achieve 1.5T will have a ‘Coil Position Device’ in an estimated 1.3% of all future sales.

When the MPS has been entered in the MRP system and the option configuration percentages are adjusted, the material requirements can be generated with an MRP run. The new material requirements are used to calculate the changed material requirements when compared to the material- demand and replenishments. The data generated provides input for the next logistical function in the supply chain. The configuration percentages are normally not used in MRP systems. MRP systems are based on actual demand data and include fully specified customer orders. In our case the demand has to be planned ahead to ensure materials are in stock to allow short customer lead times without knowing exactly what a customer wants. This introduces fluctuations in the material requirements that are shown by the MRP system dependent whether or not an order has been confirmed and processed into the MRP system or not. The configuration percentages provide a forecasting that helps in ordering the correct inventories. The MPS process is depicted in figure 6.

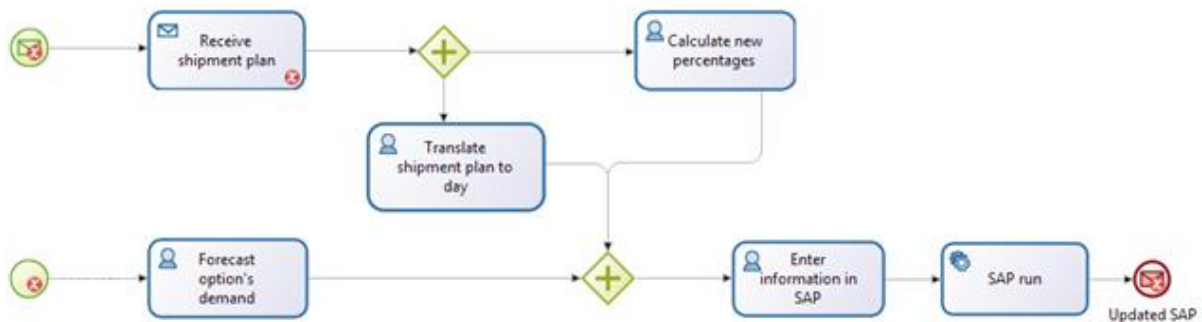


Figure 6 - MPS flow

### 6.3 MRP run

Once the MPS and option configuration have been entered in the MRP system, an MRP run can be performed. An MRP run includes various calculations that assist in the operational processes of a company. Relevant to this research is the material requirement calculation. The MRP logic for material requirement calculations comprise of the following four steps.

- *BOM explosion*
- *Netting*
- *Lot sizing*
- *Time phasing*

The four steps are performed in an iterative process for each BOM level of a finished goods BOM structure. First the material requirements for the highest level of the BOM are calculated, when done the second level of the BOM is calculated, then the third and so on. This process is performed for every product for which the material requirements need to be calculated. A complete detailed process description cannot be extracted at Philips Healthcare MR. The MRP system performing the MRP run is named *SAP*. The brain of this MRP system is not accessible due to copyright protection. However, we can safely assume it follows general MRP logic when executed. For a more detailed explanation on MRP logic can be found in chapter 2.

### 6.4 Procurement

Material requirement data is available when the proposed demand plan is translated into a daily MPS and an MRP run has been performed. This data is used by the procurement department to procure the correct materials. From the data 2 parameters are of importance: the required material quantity and date of consumption of those materials.

The procurement process initiates with calculating what additional inventory is required based on the material requirements that followed from the proposed demand plan, the current stock levels, and the planned replenishments. The calculation described is part of the process is normally performed by the MRP system. The data resulting from these calculations are used to check if any OOS situations will occur. If an OOS situation will happen, adjustments to the replenishments are made. This can either be increasing a replenishment quantity, or schedule a replenishment earlier. Both adjustments require contact with the supplier, to ensure feasibility of the adjustment. To have stable demand levels towards suppliers, a minimum lot-size for ordering is set that provides a buffer of inventory. This reduces the system nervousness in the supply chain on the upstream side (Carlson, et al., 1979).

The case environment examined at Philips Healthcare MR uses inventory management protocols called Supplier Managed Inventory (SMI), Supplier Managed and Owned Inventory (SMOI), and one-time buy inventory. These protocols are also known as or Vendor Managed Inventory (VMI) in most literature. For One-time buy inventory or SMI & SMOI a slightly different approach is used (Appendix A). For the sake of limitation these inventory management protocols are left out of scope. The complete process flow is summarized in figure 7.

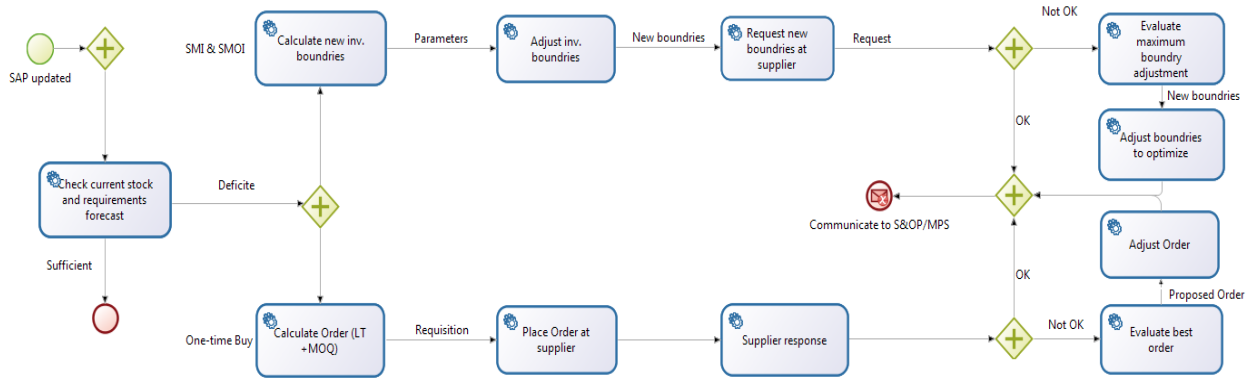


Figure 7 - Procurement process

## 6.5 Work floor

In this paragraph the work floor is briefly discussed to provide a broader understanding of the case environment. However the work floor will not form a vital part of this research.

The production environment of Philips Healthcare MR functions as a make-to-stock and pick-to-order process. The make-to-stock can be divided in two main categories: the pre-assembly of magnets, and the sub-assembly of other components that are required for either the magnets pre-assembly or for the final installation of the MRI device. The pick-to-order consists of a warehouse picking all the required components, often boxed, for shipment. This leads to the following 3 work floor capacity entities, as named by Philips Healthcare MR: (1) MR production, (2) Pre-assy and (3) Warehouse.

Each entity has their capacity limits and capacity behavior, which will now be briefly discussed.

- *MR Production*: operates with demand that originates directly from the MPS planning. The work floor capacities consist of fixed contingent workers and flex workers using a job shop environment. The flex workforce has the ability to grow and reduce based on the total demand of the planning.
- *Pre-Assy*: operates with demand that originates directly from the MPS planning. The work capacity is equally setup as *MR production* but the assembling process has complex steps. The complexity requires workers to be knowledgeable about the process. This reduces the ability to have flexible workers compared to the MR production entity.
- *Warehouse*: This is an off-site process location with a relative low level of complexity. The available capacity is a fixed total per month, which can be distributed as desired into weekly capacity.

## 6.6 Consequences of current methods

The method used to determine the changed material requirements from a proposed demand plan follows logical steps. Each step is defined and all steps are executed in series, with the exception of the two parallel paths within the procurement function. In this paragraph the method will be evaluated based on the case environment of Philips Healthcare MR. The outcome can provide feedback to management on improvement opportunities and highlight general issues related to S&OP and MRP. In this paragraph, we aim to address to consequences found or those that we anticipate that could have negative effect on the supply chain or operations.

### 6.6.1 Market buffers

The proposed demand plan that is released every S&OP cycle is based on indication from key-market representatives. The indications include future sales anticipations and current order-in-take (OIT). The order-in-take resembles the orders that are in the order book and confirmed by customers. The issue with this information system is that key-markets tend to overstate their future sale anticipation. This is done to gain a buffer of finished goods to cut lead time to customers. Such lead time cutting may be beneficial for sales but have negative impact on the supply chain. The buffer may include a wide variation of device types to be efficient, varying in mix based on the demand behavior of the market. The devices end up in the 'pipelines' of the supply chain, which means that devices that are not yet sold or attached to an order are shipped out to fulfill future demand at a key-market while being located at a warehouse. Such practices lead to increase in inventory owned by Philips Healthcare MR and the relatively high value of the finished goods result in a poor an inventory balance. Also, the inventory turn-over period is prolonged by this (Langenkaemper, 2015), which is an indicator on how good a supply chain and its inventory is controlled.

### 6.6.2 Sales targets

In addition to the increase of buffers between manufacturing and sales-channels, the key-markets use sales targets to drive sales performance. The sales targets used can often be set too high in comparison to the health of the market. This leads to sales targets that are infeasible. When sales targets are not met, the unsold finished goods get stuck in the supply chain. This means that the liquidity of the economic balance decreases and reduces overall business performance. I.e., the money held in the finished goods can't be used for other business transactions that can generate revenue. This leads to further reduction of the inventory turn-over period. To solve this issue, fewer finished goods are promised to the key-markets based on their sales history. The most dangerous consequence to this is that the key-markets 'learn' that they are provided with fewer devices than they originally asked for because history showed that the devices remained unsold. As a reaction the representative of the key-markets inflate their own demand forecast to counter the reduction.

### 6.6.3 Pushed demand vs pulled demand

The method used to determine a proposed demand plan and to generate the material requirements, start with input from the key-markets. The markets provide a demand based on their sales forecasts. This demand forms a request up the supply chain to produce sufficient MRI devices. The demand that is processed into the MRP system is adjusted by the S&OP department due to the previously described sales targets issue. The logic forms a pull process, where demand is pulled towards the market. Also an MRP system normally serves as a pull system. The system calculates capacity and material requirements based on expected output (sales). However, during the analysis of the material requirement calculations, we noticed that the process showed signs of a push system. The MRI devices are scheduled as slots by the MPS and the order desk fills the slots with actual sales data from the markets. The key-market sales engineers will be able to receive an MRI device to distribute to a customer based on when slots are available. This means that the sales engineer can only sell what has been scheduled. Now the direction of the flow of the supply chain has changed from a pull system to a push system. The downside of this method is that when demand fluctuations are relatively high, the markets will have little access to additional devices for sales, or excess inventory will remain in the 'pipelines' of Philips Healthcare MR.



#### 6.6.4 Proposed demand plan accuracy

A proposed demand plan is based on key-market input. Over this input, the S&OP department provides an effort to reduce the forecasting errors previously mentioned by faulty information from the key-markets representatives. With analytical tools, the accuracy is improved. However, the proposed demand plan still has a low level of accuracy when comparing actual sales to each demand plan over the last 12 months. In addition, the plan can fluctuate by relatively large amounts per month. With these two reasons the proposed demand plan is difficult to use as true demand. Departments that rely on the information provided from the proposed demand plan tend to have reduced faith in the accuracy of the plan, based on their previous experiences with it. This leads to a different process approach. Normally data from the plan would generate material requirements. When trust in the plan diminishes, the feasibility of it will not be judged honestly. Employees will tend to provide feedback based on their past experiences and accept the plan as it is, and use MRP data in future states of the supply chain as actual demand requirements. This leads to capacity issues in the future by not anticipating enough. An example of this is the OOS list that an MRP system generates. The list includes all OOS situations within a set time frame and is seen as a list that procurement employees use to initiate their working process, instead of avoiding OOS situations. This error solving method changes the process from a controlled MRP system to a delayed error fixing system. Working with such a mentality will deteriorate the ability to respond quickly to the market and increases inventory positions.

#### 6.6.5 Proposed demand plan value

Next to the accuracy of the proposed demand plan, the operational value of the plan is degraded due to its manufacturing complexity. The proposed demand plan provides insight on finished goods but it provides almost no understanding of material requirements and material requirement changes. Especially when finished goods have complex BOM structures, which is one of the core problems this research tries to tackle. In the case examined, the finished goods have 10 BOM layers and between 600 and 1400 materials per device that are controlled in the supply chain by the operational departments. With such a complex BOM, it cannot be expected that every employee has the knowledge of the BOM structures for each product in detail to estimate what the impact of a proposed demand plan is on material level. This consequence is the main problem this research tries to solve.

#### 6.6.6 Work floor capacity

The proposed demand plan has the behavior of fluctuating relatively much between planning cycles. This is partially caused due to the inaccuracy of the proposed demand plan. Preferably the first 3 months in the demand plan should not show any major changes in demand. If such changes are present, the work floor capacity will have difficulty following it. In addition to not being able to cope with fluctuation in time, the available work floor capacity can be too high or too low from the start. Both reasons given make it difficult to accurately determine the required work floor capacity and have led to the following effects.

- Last minute capacity increases with additional costs
- Missed due dates
- Sending staff home mid-week and compensate working hours on other working days (including weekends)



Fluctuating work floor requirements and changing work schedules correlates with a decreased job satisfaction (Andresen & Domsch, 2007). Measures to reduce such fluctuations should be taken into consideration.

#### 6.6.7 Department separation

The MRP logic provides a step-by-step protocol that determines the material requirements and changes in material requirements. One department follows another in the information flow. This creates an environment where responsibilities are handed over in full whenever a certain function is finished. Between the MPS and procurement department, which are the most prominent in the scope of this research, this phenomenon is visible. Such working ethics creates a gap between departments and decreases overall supply chain and information flow efficiency. The issue has been mentioned by employees that are both directly and indirectly involved in the processes at scope in this research. Due to the sensitivity of this consequence, no further elaboration or sources will be provided in this report. The issue described is a managerial one and improvements can be made with the support of the management.

#### 6.6.8 Slot planning

The slots allocated by MPS planners correlate to specific shipping dates. The slots are often rescheduled close to the due-date. Planners are prone to reschedule due to the large fluctuations in actual demand versus the proposed (expected) demand. When material lead times are relatively long it can be a challenge to get the materials in time for the changed due-dates. The consequence is that due-dates can be missed when materials are late or inventory levels build up when materials are buffered to cope with demand fluctuations.

### 6.7 Conclusion on RQ 1 & 2

This section answers research question 1 and 2, which are the following:

- 1) *How is Philips Healthcare MR calculating material requirements to meet scheduled demand, with the use of an MRP system?*
- 2) *What are the consequences of the methods used in this process?*

Research question 1 is a descriptive question, providing insight in part of the work flow at Philips Healthcare MR. The steps that are taken to go from a proposed demand plan to a material requirement overview are examined. Prior to researching the current method at Philips Healthcare MR we knew it would closely resemble standard MRP logic, because an MRP system is used. We also conclude after investigation that the method closely resembles MRP logic. The process included the use of BOM structures and BOM explosion, which are standard to MRP logic. The only slight difference was the use of a daily MPS instead of a monthly MPS. The MPS is a common step performed when an MRP system is present in a manufacturing environment; however it is not an integral part of MRP software packages. At Philips Healthcare it was created manually, because of the need for a daily MPS to meet the demand for planning accuracy. We did however find a key step that is not always found in MRP logic, which is considered to be vital for the material requirement calculation process. The step is described as the configuration percentage, which gives the probability that an optional component is included in future sales, based on historical averages and known customer orders. It is important when calculating the correct material requirement for materials that are used in the optional components. The configuration percentage is also calculated

manually and then entered into the MRP system. Thus, we conclude that MRP logic is used, with additional steps.

The second research question covers the consequences that the current process at Philips Healthcare MR holds. Although the entire process described follows a clear pattern where one process is followed up by another, in practice some negative effects are observed. There are 8 consequences observed which all are related to the process. Most of them are either forecast accuracy related consequences or sociological related phenomena, meaning that the human interaction with the logistical system causes consequences to occur. The consequences have a negative influence on the efficiency of the supply chain and the logistical aspects of the supply chain. It is believed that the consequences can be improved or solved with managerial efforts.

## 7. Essential MRP aspects

This chapter evaluates the process description provided in the first part of the research. The aim of this chapter is to identify which aspects of the material requirement generation method used at Philips Healthcare MR are essential to be included in a method to assist in the assessing of the proposed demand plan on its feasibility. This chapter will answer research question 3 and corresponds to stage 2 of the SDLC method. In section 7.1 the key aspects are evaluated that are essential for a solution based on the description provided by research question 1 and 2. In section 7.2 important parameters are discussed. Section 7.3 provides answers to research question 3.

### 7.1 Key aspects

In the first part of the research we found that multiple operational functions are combined to go from a monthly finished goods list to a material requirement plan. The operational functions provide all the input data for the MRP system to perform an MRP run. The output of the MRP run can be used to aid in operational activities. The described functions included; (1)S&OP, (2)MPS, (3)Configuration forecasting, (4)MRP Run, (5)Procurement, and (6)Work floor. This research will cover the first four functions. From the total process the following aspects are considered essential in producing material requirements from a demand plan:

- Proposed demand plan
- BOM structure
- Configuration percentage

The proposed demand plan forms the initial data of the process. It includes a list of finished goods and their required quantities per planning cycle (month). The finished goods in our case environment are Back-ends, Magnets, and Upgrades. This list also serves as an overview of which BOM structures are required. The BOM structure holds all the finished-good-specific material requirements. Exploding it with common MRP logic is arguably the easiest way to gain insight to material demand. However, a consideration here is that a BOM explosion can be a hefty calculation and within fast developing industries such as the high-tech, the BOM is an ever changing material list.

When exploding the BOM, the configuration percentages play an important role in accurate material demand. These percentages are usually only calculated for first level materials in the BOM. The percentages are also exploded to all other BOM levels to obtain correct quantities for all materials.

For example: if a first level component is forecasted with a percentage of 50, all the materials that are underneath this first level material should also have this forecasted percentage. Or it can be translated to a quantity multiplication of 0.5.

When combining the proposed demand plan with BOM structures and configuration percentages, an accurate material demand overview can be calculated. This method can be illustrated as depicted by Figure 8.

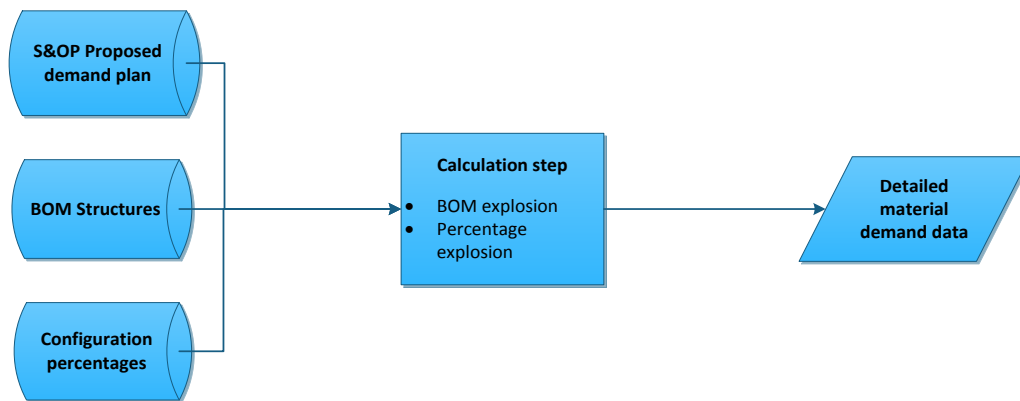


Figure 8 - Proposed method concept

## 7.2 Parameters

Each essential aspect in the mentioned work flow of Philips Healthcare MR holds several parameters that are important for the execution of the process. This section evaluated the essential aspects with the aim to extract parameters that are essential when proposing a solution.

### 7.2.1 Proposed demand plan

The proposed demand plan holds the following parameters that are considered important.

- *Finished goods*: it indicates how many finished goods of a specific type are required. This is essential when calculating material requirements
- *Time frame*: the demand plan is separated per planning cycle (month), providing a time frame to place material requirements in. Material requirements are assessed per time interval
- *Quantity indication*: it indicates how many of a specific finished good is required within a specific time frame.

### 7.2.2 BOM structure

The BOM structure holds information about all materials required to manufacture 1 unit of finished goods and all relations between materials within the BOM that indicate which material is required in which assembly. In the BOM the following parameters are considered important.

- *Material identification code*: this code is unique to each material throughout the supply chain. Because one material can be found in different BOM structures the requirements for a specific materials over all BOM structures needs to be combined. The material identification code provides a way to look up each material.
- *Material description*: it does not is a directly important parameter for calculation purposes but it assist in reading data lines when a material description is linked to a material identification code
- *BOM level code*: this indicates on which level of the BOM structure a material is found. It can be so that a material is found on multiple levels.
- *Higher level material*: the relations between materials are indicated by what the higher level material (1 BOM level up) of a specific material at a specific BOM level is. A material can be present multiple times within 1 BOM structure and on different BOM levels. To perform

correct BOM explosion it is important to know what the higher level material of specific material found at a specific spot in the BOM structure is.

### 7.2.3 Configuration percentage

The configuration percentage is an important parameter from the process description. It provides a forecasted configuration of finished goods when calculating material requirements. The percentage is only provided for the first level of the BOM as discussed earlier. For correct material requirements it is important that this parameter is exploded correctly through the BOM to all lower level materials.

## 7.3 Conclusion RQ 3

This section answers research question 3, which is the following:

- 3) *Which aspects, used in the Philips Healthcare MR MRP logic, are essential to the generation of correct material requirement data?*

Research question 3 aims to further distil information from the process description of research question 1 and 2. We concluded that the proposed demand plan, BOM structures and the configuration percentages are essential aspects when calculating material requirements. The proposed demand plan and BOM structures are standard MRP logic, the configuration percentages is however not included in standard MRP logic. In the next part of the research these 3 aspects will function as building blocks when modelling a solution.

## Part II: Method proposition

# 8. Calculate material requirement changes

In this chapter a method will be proposed to translate a proposed demand plan into material requirement and material requirement changes, without entering demand data into an MRP system. The chapter will start with illustrating the requirements of the method in section 8.1. In section 8.2 evaluates the design of the solution and its logic. Section 8.3 describes issues that are expected to be common. The chapter concludes with section 8.4 answering research question 4.

## 8.1 Design criteria

The method proposed will have to comply to design criteria that will assist with implementation into business environments. The established design criteria are based on responses from end-users. Implementing the method is the subject of stage 3 of the SDLC method and research question 5 of this thesis. However, they are described now because they have influence on modelling decisions.

### 8.1.1 Spreadsheet compatible

To ensure easy business implementation of a solution to the problem a simple programming environment must be used. The majority of employees in manufacturing firms are capable of using spreadsheet based software. Knowledge of more advanced programming platforms is often limited to professionals.

### 8.1.2 Updatability

Product catalogues of manufacturing companies can be relatively fast-developing, especially in the high-tech sector. Changes can include in- and out phasing of finished goods or upgrades. Fast developing catalogue means that changes to the content of a proposed demand plan occur. To be able to handle such changes, the method requires adding and removing finished goods from the list with relative ease. This is referred to as updatability of the method.

### 8.1.3 Input

Because of the updatability criteria, the input data is required to be easily updatable as well. BOM structures are subject to changes. Finished goods with high-tech characteristics often have multiple changes to a BOM per planning cycle. Changes often occur due to material development, new materials entering the supply chain, and current materials switching suppliers. This most likely means that each time the method is used, the input data needs to be updated. It is important for business implementation that users can easily update all input data.

### 8.1.4 Output

The method is developed to provide assistance when assessing the feasibility of a proposed demand plan. Incorrect material requirement and material requirement change information can lead to faulty judgement, there for a high level of data accuracy and data validity of the output data is desired. Manufacturers have to check whether or not suppliers can provide the required materials in time. When a proposed demand plan introduces changes to the quantities of materials required, consultation based on the changes with suppliers is required to assure feasibility.

## 8.2 Design

In this section a method is proposed to address the research problem. The concept will be evaluated step-by-step, in chronological order.

### 8.2.1 Input data

Based on the process description in this paper the following aspects are essential to determine material requirements:

- BOM structures of all finished goods
- Proposed demand plan
- Configuration percentage of all level 1 materials per BOM

Each data source will now be discussed.

#### BOM structures

Because a spreadsheet environment is required by the design criteria, a BOM structure will be presented as a list. Common is that material relations in the BOM are defined by level and higher level material. BOM structures as a list can be extracted from most MRP systems used in manufacturing industries. The method to retrieve them may vary from case to case but normally is not too difficult. In Table 8 a piece of an example BOM structure is shown.

Table 8 - BOM structure example

Mat Code	Mat Description	Quantity	Lvl /	Pur. Group	IMP	Higher Mat	Higher Mat Description
989603024232	INGENIA BASIC SYSTEM SET 3.0T	1,00	002 A	L92	M1	989603027053	ASSEMBLED MAGNET WA 3.0T HP BR
989603024232	INGENIA BASIC SYSTEM SET 3.0T	2,00	002 A	L92	M1	989603028302	MP Ingenia 3.0T HP
989603024232	INGENIA BASIC SYSTEM SET 3.0T	1,00	002 A	L92	M1	989603028422	MP Ingenia 3.0T HP FC
989603026193	PRE-ASSY SYSTEMCOVERS WA	1,00	002 A	81,00	Z2	989603028302	MP Ingenia 3.0T HP
989603026193	PRE-ASSY SYSTEMCOVERS WA	1,00	002 A	81,00	Z2	989603028422	MP Ingenia 3.0T HP FC
989603028302	MP Ingenia 3.0T HP	55,00	001	L92	M0	P781491001	PBOM FOR 781491
989603028422	MP Ingenia 3.0T HP FC	45,00	001	L92	M0	P781491001	PBOM FOR 781491

On the left side, the materials are identified by a number and description, followed by quantity, BOM level, ABC category, purchasing group, and inventory management protocol. The last 2 columns indicate what the higher level material of the material specified in the first column is. The quantity column shows a configuration percentage for level 1 BOM items, and an actual quantity for all lower levels. The configuration percentage is discussed in section 8.2.2

For example, we can see that 2 units of a *Basic System Set* are required for the higher level material *MP Ingenia 3.0T HP*.

With the higher level material indication, the relations of materials within a BOM structure are defined. With high complexity of BOM structures the material relations are difficult to determine. The first to second level relation, as in the example, is manageable. Trying to relate multiple levels deep over multiple materials is too complex without the use of a calculation system.

#### Proposed demand plan

The proposed demand, as discussed in chapter 6, is a forecasted demand plan that provides required quantities of finished goods per time interval. In Table 9 the same example is provided as in chapter 6.

Table 9 - Proposed demand example

Proposed shipment/slot plan																	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Q1	Q2	Q3	Q4
Leopard Wave 4	1	1	1	1	1	1	1	1	1	1	1	6	17	3	3	3	8
Multiva 1.5T 8 R5	1	4	1	3	3	1	2	1	1	1	2	1	21	6	7	4	4
Multiva 1.5T R5	5	4	6	12	8	6	10	10	8	8	8	5	90	15	26	28	21
Achieva 1.5T Total	11	11	9	16	14	11	14	14	13	14	12	5	144	31	41	41	31
Achieva 1.5T	4	5	2	10	7	5	7	7	7	7	7	2	70	11	22	21	16
Achieva 1.5T R5	7	6	7	6	7	6	7	7	6	7	5	3	74	20	19	20	15
Ingenia 1.5T Total	20	24	23	33	27	26	38	31	30	30	29	20	331	67	86	99	79
Ingenia 1.5T	1	1	1	2	2	2	1	2	2	1	3	1	19	3	6	5	5
Ingenia 1.5T R5	16	17	16	26	20	20	29	23	22	23	21	14	247	49	66	74	58
Ingenia 1.5T S	1	1	1	1	1	1	1	1	1	1	1	1	12	3	3	3	3
Ingenia 1.5T CX	1	3	4	1	1	1	1	1	1	1	1	1	17	8	3	3	3
Ingenia 1.5T CX ZBO	1	2	1	3	3	2	6	4	4	4	3	3	36	4	8	14	10
Achieva TX Total	4	3	3	7	5	4	3	4	5	5	4	3	50	10	16	12	12
Achieva TX	1	1	1	3	2	2	1	2	3	3	3	2	24	3	7	6	8
Achieva TX R5	3	2	2	4	3	2	2	2	2	2	1	1	26	7	9	6	4
Ingenia 3.0T Total	10	16	14	22	22	15	25	19	17	13	9	9	191	40	59	61	31
Ingenia 3.0T	2	1	2	5	4	2	8	3	5	4	2	3	41	5	11	16	9
Ingenia 3.0T R5	7	13	8	14	14	9	14	12	9	5	4	4	113	28	37	35	13
Ingenia 3.0T CX	1	2	4	3	4	4	3	4	3	4	3	2	37	7	11	10	9
Panorama HFO	1	1	1	1	2	1	1	1	1	1	1	1	13	3	4	3	3
<b>Total</b>	<b>53</b>	<b>64</b>	<b>58</b>	<b>95</b>	<b>82</b>	<b>65</b>	<b>94</b>	<b>81</b>	<b>76</b>	<b>73</b>	<b>66</b>	<b>50</b>	<b>857</b>	<b>175</b>	<b>242</b>	<b>251</b>	<b>189</b>
		175			242			251						189			
		20,4%			28,2%			29,3%						22,1%			

### Configuration percentage

As described in chapter 6, the configuration percentage provides a forecast on the configuration of future sales of finished goods. This percentage is important when calculating material requirements. Often the configuration percentage is found on the first level in a BOM list. Instead of required quantities of a component, a configuration percentage is given. In the case environment of this research, the configuration percentage is included in the BOM list when extracted. If the configuration percentage is not present when extracting a BOM list, it can be added manually in an additional column afterwards.

The input data can be formalized as following

$$D_{i,t}^{New} \geq 0 \text{ for all } i \in \{1,2, \dots, I\} \text{ and all } t \in \{1,2, \dots, T\}$$

$$D_{i,t}^{Old} \geq 0 \text{ for all } i \in \{1,2, \dots, I\} \text{ and all } t \in \{1,2, \dots, T\}$$

where

$$D_{i,t}^{New} = \text{required demand in the new situation of finished good } i \text{ in time period } t$$

$$D_{i,t}^{Old} = \text{required demand in the old situation of finished good } i \text{ in time period } t$$

$$L_{i,m} \in \mathbb{N} \text{ for all } i \in \{1,2, \dots, I\} \text{ and all } m \in \{1,2, \dots, M\}$$

$$P_{i,m} \in [0,1] \text{ for all } i \in \{1,2, \dots, I\} \text{ and all } m \in \{1,2, \dots, M\} \text{ with } L_{i,m} = 1$$

where

$$L_{i,m} = \text{Level of material } m \text{ in BOM of finished good } i$$



$P_{i,m}$  = configuration percentage of material  $m$  for finished good  $i$ , which represents the fraction of finished good  $i$  that opt to use material  $m$

Based on the case environment a list of important (logistical) parameters is made that are found important to be added to the output data. The parameters are not directly related to the calculation process, but assist in interpreting output data. The parameters are extracted from the MRP system and can be linked to individual materials in the output data of the method.

- *ABC category*: materials fall into the ABC category based on their annual consumption value. This categorization indicates the importance of a material on the inventory balance. Materials with a high annual consumption value category have a bigger impact on the inventory balance and are therefore more crucial to be monitored for changes as a result from a new demand plan. Filtering on this parameter can be a useful tool to search through large lists of materials (Appendix B).
- *Buyers group*: indicates to which procurement employee the material logistical responsibilities belong. An employee can filter on the buyer group to retrieve material information important to him or her.
- *Vendor identification*: This provides another filter option to retrieve material information more quickly.
- *Stock type*: indicates what type of inventory management protocol is used. This enables to filter out data that is VMI controlled.

The parameters mentioned above provide basic information to assess the changes per planning cycle of a proposed demand plan. In the case used for this research additional specific parameters were used (Appendix C).

### 8.2.2 Method

A proposed method will have to be able to work with the provided data sources in a spreadsheet environment. To avoid calculation difficulties within a spreadsheet environment, we propose a three phase calculation approach. In the first phase the material requirements are calculated for one specific finished good. The requirements for the proposed demand plan and the previous proposed demand plan are calculated. This is done for all different finished goods, one at a time. In the second phase all material requirements are summed up based on individual material identification, with one table for the proposed material requirements and one for the previous or current situation. The third phase makes a comparison between the two situations by calculating the material requirement changes per month in terms of absolute quantity and percentile change. Phase two and three will be discussed in section 8.2.3, as they are considered output data.

For the first phase the following steps apply:

- 1) *Multiply all materials on level 1 with proposed demand to obtain non-configured requirements for all first level materials.*
- 2) *Multiply non-configured demand with configuration percentage to obtain configured requirements for all first level materials.*
- 3) *Move one BOM level down*
- 4) *Multiply required quantity with higher level calculated requirements*
- 5) *Iterate step 3 and 4 until all BOM levels are calculated*

Table 10 is a copy of Table 8 and the proposed demand data for the *Ingenia 3.0T* of Table 9. Table 10 provides an example for the calculation steps of the first phase of the proposed method.

Table 10 - Method calculation example

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Q1	Q2	Q3	Q4
Ingenia 3.0T	2	1	2	5	4	2	8	3	5	4	2	3	41	5	11	16	9

Mat Code	Mat Description	Quantity	Lvl /	Pur. Group	IMP	Higher Mat	Higher Mat Description
989603024232	INGENIA BASIC SYSTEM SET 3.0T	1,00	002 A	L92	M1	989603027053	ASSEMBLED MAGNET WA 3.0T HP BR
989603024232	INGENIA BASIC SYSTEM SET 3.0T	2,00	002 A	L92	M1	989603028302	MP Ingenia 3.0T HP
989603024232	INGENIA BASIC SYSTEM SET 3.0T	1,00	002 A	L92	M1	989603028422	MP Ingenia 3.0T HP FC
989603026193	PRE-ASSY SYSTEMCOVERS WA	1,00	002 A	81,00	Z2	989603028302	MP Ingenia 3.0T HP
989603026193	PRE-ASSY SYSTEMCOVERS WA	1,00	002 A	81,00	Z2	989603028422	MP Ingenia 3.0T HP FC
989603028302	MP Ingenia 3.0T HP	55,00	001	L92	M0	P781491001	PBOM FOR 781491
989603028422	MP Ingenia 3.0T HP FC	45,00	001	L92	M0	P781491001	PBOM FOR 781491

Looking at

Table 10 we can illustrate the following example.

- The proposed demand plan at the top of the table indicates that 5 units of *Ingenia 3.0T* are forecasted in April.
- The BOM list shows that on level 1 a regular *HP* and a *HP FC* material is required to manufacture 1 unit of *Ingenia 3.0T* (indicated by higher level material *PBOM FOR 781491*),.
- Thus, the non-configured requirement of both the regular *HP* and *HP FC* materials in April is 5 units.
- The materials on BOM level 1 have a configuration percentage in the quantity column. All other BOM levels have a required quantity on the quantity column.
- The configuration percentage of the regular *HP* is 55% and 45% for the *HP FC* as indicated in the quantity column.
- This leads to configured requirements in April of  $5 * 0.55 = 2.75$  units for the regular *HP* and  $5 * 0.45 = 2.25$  for the *HP FC*.
- Both the regular *HP* and *HP FC* material are the higher level materials of the *Basic System Set*.
- The *Basic System Set* is required 2 times in the regular *HP* and 1 time in the *HP FC*.
- Thus, the summed requirements for the *Basic System Set* is  $(2.75*2) + (2.25 * 1) = 7.75$

The first phase can be formalized as following.

$$B_{m_1, m_2}^i \text{ for all } i \in \{1, 2, \dots, I\} \text{ and all } m_1 \in \{1, 2, \dots, M\} \text{ and all } m_2 \in \{1, 2, \dots, M\}$$

$$\text{with } B_{m, m}^i = 1 \text{ for all } m \in \{1, 2, \dots, M\}$$

$$B_m^i \geq 0 \text{ for all } m \in \{1, 2, \dots, M\} \text{ with } L_{i, m} = 1$$

where

$$B_{m_1, m_2} = \text{quantity required of material } m_1 \text{ to produce 1 piece of material } m_2 \text{ as determined via standard BOM-explosion}$$

$B_m^i$  = quantity required of material  $m$  with BOM-level = 1, to produce 1 piece of end-item  $i$ , provided that material  $m$  is selected as an operational material

### 8.2.3 Output data

The second phase of the calculations consisted of summing up the requirements per material code that are calculated for each individual BOM, both for the new situations and the old situation. This can be formalized as following.

for all  $m \in \{1,2, \dots, M\}$  and all  $t \in \{1,2, \dots, T\}$  we calculate the following

$$RQ_{m,t}^{New} = \sum_{i=1}^I D_{it}^{New} * \sum_{\substack{m_2 \in \{1, \dots, M\} \\ \text{Such that } L_{im_2}=1}} \hat{B}_{m_2}^i * P_{i,m_2} * B_{m,m_2}$$

$$RQ_{m,t}^{Old} = \sum_{i=1}^I D_{it}^{Old} * \sum_{\substack{m_2 \in \{1, \dots, M\} \\ \text{Such that } L_{im_2}=1}} \hat{B}_{m_2}^i * P_{i,m_2} * B_{m,m_2}$$

where

$RQ_{m,t}^{New}$  = total requirements of material  $m$  in time period  $t$  in the new situation

$RQ_{m,t}^{Old}$  = total requirements of material  $m$  in time period  $t$  in the old situation

As described earlier, the changes in material requirements of a proposed demand plan in comparison with a previous situation are considered important data, which is the third phase of the calculations. The absolute changes as well as the degree to which requirements vary (percentage) per month is a good indicator to assess the feasibility of a proposed demand plan. To calculate the changes the material requirements for the proposed demand plan and the current situation need to be calculated first. When both situations are calculated the absolute changes can be easily computed by subtracting the new material requirements from the old. The absolute changes can then be expressed as a percentage of change (increase/decrease) between the old and new situation. The formalization of the last phase is as following.

$$\Delta Q_{m,t} = RQ_{m,t}^{New} - RQ_{m,t}^{Old}$$

$$\Delta\%_{m,t} = \left( \frac{RQ_{m,t}^{New} - RQ_{m,t}^{Old}}{RQ_{m,t}^{Old}} \right) * 100 \text{ if } RQ_{m,t}^{Old} > 0$$

where

$\Delta Q_{m,t}$  = absolute change in quantity of material  $m$  in time period  $t$  between the old and new situation

$\Delta\%_{m,t}$  = percentile change in quantity of material  $m$  in time period  $t$  between the old and new situation

The framework of the proposed demand plan combined with the material lists of the BOM's forms a suitable lay-out for the output data. This results in each material being identified with the material

code with material requirement changes per time interval. Combining the output lay-out with the logistical parameters and the output data from the method a complete output format can be formed. Table 11 to Table 15 depicts an example of the output format.

**Table 11 - Method output: Material information**

Material	Description	Purchasing Group	Vendor	ABC Indicator	IMP
989603008225	Trolley	081 (Teunis, Eric)	9622708 B (Material - Medium Significance)		PD (MRP)
989603011603	SENSE Knee Coil 1.5T 8Ch	060 (T. Loots)	162287 B (Material - Medium Significance)		Z1 (Noct: SMI (-Plan;+SDreqs))
989603012132	EARTHQUAKE BRACKETS	014 (Burgt, Anne van de)	9396974 B (Material - Medium Significance)		PD (MRP)
989603013051	SENSE BREAST MATTRESS	035 (Hendriks, Ans)	9184128 B (Material - Medium Significance)		YN (SNC: SMI (-Plan;+SDreqs))
989603013413	BBC, 1.5T PMS 7CH, ACHIEVA (DS)	060 (T. Loots)	162287 B (Material - Medium Significance)		Z1 (Noct: SMI (-Plan;+SDreqs))
989603013432	SENSE Shoulder Coil 1.5T 4Ch	060 (T. Loots)	162287 B (Material - Medium Significance)		Z1 (Noct: SMI (-Plan;+SDreqs))
989603014884	SENSE Foot Ankle Coil 1.5T 8Ch	060 (T. Loots)	162287 A (Significant Material)		Z1 (Noct: SMI (-Plan;+SDreqs))
989603017031	KNEE FOOT ANKLE COIL 1.5T	035 (Hendriks, Ans)	9606556 A (Significant Material)		Y2 (SNC: SOI (-Plan;+SDreqs))

**Table 12 - Method output: Requirements proposed demand plan**

Material requirements proposed demand plan																
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Q1	Q2	Q3	Q4
4,5	4	4,8	6,1	2,55	4	4,75	7,7	6,15	5,6	6,35	1,4	57,9	13,3	12,65	18,6	13,35
6,35	7,7	6,25	8,75	6,85	5	7,8	12,85	11,45	10,9	10,85	1,4	96,15	20,3	20,6	32,1	23,15
2	2,48	3,41	2,16	2,48	0,9	2,83	4,1	3,98	3,7	3,69	1,16	32,89	7,89	5,54	10,91	8,55
6,15	6,85	5,5	8	7,35	3,85	7,6	12	12,35	11,75	10,95	1,2	93,55	18,5	19,2	31,95	23,9
3,64	5,12	4,13	5,65	3,16	4,06	4,53	8,73	6,33	6,41	6,07	1,3	59,13	12,89	12,87	19,59	13,78
4,34	4,66	5,45	4,81	3,16	2,9	4,39	6,31	6,77	5,65	6,27	1,66	56,37	14,45	10,87	17,47	13,58
2,44	3,06	3,1	3,41	2,11	2,3	3,04	5,21	4,42	4,25	4,17	0,96	38,47	8,6	7,82	12,67	9,38
3,6	3,65	4,35	4,3	2,2	2,9	3,8	5,9	5,3	4,4	5,3	1,3	47	11,6	9,4	15	11

**Table 13 - Method output: Requirements previous demand plan**

Material requirements previous demand plan																
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Q1	Q2	Q3	Q4
4,5	4	4,8	6,1	2,55	4	7,45	6,4	4,75	4,45	4,6	1,4	55	13,3	12,65	18,6	10,45
6,35	7,7	6,25	8,75	6,85	5	11,5	10,75	9,85	10,2	9,15	1,4	93,75	20,3	20,6	32,1	20,75
2	2,48	3,41	2,16	2,48	0,9	4,5	3,63	2,78	2,99	2,27	1,16	30,76	7,89	5,54	10,91	6,42
6,15	6,85	5,5	8	7,35	3,85	9,7	11,7	10,55	10,95	9,6	1,2	91,4	18,5	19,2	31,95	21,75
3,64	5,12	4,13	5,65	3,26	4,11	8,98	5,93	5,28	5,41	5,12	1,3	57,93	12,89	13,02	20,19	11,83
4,34	4,66	5,45	4,81	3,22	2,93	7,27	6,18	4,38	4,61	4,82	1,66	54,33	14,45	10,96	17,83	11,09
2,44	3,06	3,1	3,41	2,17	2,33	5,42	4,18	3,43	3,56	3,42	0,96	37,48	8,6	7,91	13,03	7,94
3,6	3,65	4,35	4,3	2,2	2,9	6,15	5,15	3,7	3,75	3,75	1,3	44,8	11,6	9,4	15	8,8

**Table 14 - Method output: Requirement changes of proposed demand plan**

Material requirement changes of proposed demand plan																
Δ Jan	Δ Feb	Δ Mar	Δ Apr	Δ May	Δ Jun	Δ Jul	Δ Aug	Δ Sep	Δ Oct	Δ Nov	Δ Dec	Δ Total	Δ Q1	Δ Q2	Δ Q3	Δ Q4
0	0	0	0	0	0	-2,7	1,3	1,4	1,15	1,75	0	2,9	0	0	-2E-15	2,9
0	0	0	0	0	0	-3,7	2,1	1,6	0,7	1,7	0	2,4	0	0	-2E-15	2,4
0	0	0	0	0	0	-1,67	0,47	1,2	0,71	1,42	0	2,13	0	0	0	2,13
0	0	0	0	0	0	-2,1	0,3	1,8	0,8	1,35	0	2,15	0	0	2,7E-15	2,15
0	0	0	0	-0,1	-0,05	-4,45	2,8	1,05	1	0,95	0	1,2	0	-0,15	-0,6	1,95
0	0	0	0	-0,06	-0,03	-2,88	0,13	2,39	1,04	1,45	0	2,04	0	-0,09	-0,36	2,49
0	0	0	0	-0,06	-0,03	-2,38	1,03	0,99	0,69	0,75	0	0,99	0	-0,09	-0,36	1,44
0	0	0	0	0	0	-2,35	0,75	1,6	0,65	1,55	0	2,2	0	0	0	2,2

**Table 15 - Method output: Percentile changes**

Material requirement changes or proposed demand plan in %																
Δ Jan	Δ Feb	Δ Mar	Δ Apr	Δ May	Δ Jun	Δ Jul	Δ Aug	Δ Sep	Δ Oct	Δ Nov	Δ Dec	Δ Total	Δ Q1	Δ Q2	Δ Q3	Δ Q4
0%	0%	0%	0%	0%	0%	-36%	20%	29%	26%	38%	0%	77%	0%	0%	14%	64%
0%	0%	0%	0%	0%	0%	-32%	20%	16%	7%	19%	0%	29%	0%	0%	4%	25%
0%	0%	0%	0%	0%	0%	-37%	13%	43%	24%	63%	0%	105%	0%	0%	19%	86%
0%	0%	0%	0%	0%	0%	-22%	3%	17%	7%	14%	0%	19%	0%	0%	-2%	21%
0%	0%	0%	0%	-3%	-1%	-50%	47%	20%	18%	19%	0%	50%	0%	-4%	18%	37%
0%	0%	0%	0%	-2%	-1%	-40%	2%	55%	23%	30%	0%	67%	0%	-3%	17%	53%
0%	0%	0%	0%	-3%	-1%	-44%	25%	29%	19%	22%	0%	47%	0%	-4%	10%	41%
0%	0%	0%	0%	0%	0%	-38%	15%	43%	17%	41%	0%	78%	0%	0%	20%	59%

Table 15 shows that in July the majority of material requirements drop, indicating that replenishment quantity and/or frequency can be lowered. In August to December the material requirements increase significantly, indicating that replenishments quantities and/or frequency need to be increased to meet demand.

### 8.3 Common issues

This section discusses issues that are or will be prone to occur for manufacturing companies when setting up the proposed or similar tools based on the proposed method. The aim is to provide an overview which can assist in preventing these issues of having a large impact when setting up a tool with the method proposed.

#### 8.3.1 Obtaining BOM relations

As depicted in Table 10, the material list of a device contains all materials required. To be able to use the BOM structure for calculations, the BOM list should include the higher level material for each material. From this, the material relations can be obtained through BOM explosion in a spreadsheet environment. However, it is a rather unclear overview from the start. In some cases higher level material information may not be available. This presents a difficulty that should be solved before the start of programming a tool.

#### 8.3.2 Large amounts of data

Using BOM structures results in large amounts of rows of data. This can lead to difficulties in processing on a computer. The calculation power required for this depends on the amount of data included. If a tool is developed it should be able to run on a computer with standard calculation abilities. To avoid incompatibility with hardware, the programmed calculations should be performed in phases. This will reduce the required processing power of a computer.

#### 8.3.3 Data validity

The volume of output data depends on the volume of input data such as the materials within BOM structures. Data volume can build up quickly and increases the change of data invalidity due to calculation or programming mistakes. The responsible programmers should pay attention in making no mistakes in calculations, especially when integrating formulas in cells that work in the background. The validity of the method and programmed tool for Philips Healthcare MR will be discussed in part III of the research.

#### 8.3.4 Lead time

Lead time off setting is a common step in an MRP system. Lead time off setting ensure that the required material quantities are stated in the time interval when they should be ordered, which means that the lead time of the supplier is taken into account. The MRP system uses fixed values as lead times that have been entered. In practice it is often the case that the lead times of suppliers can vary heavily based on what changes in material requirements are requested and the current state of demand at the supplier. Often lead times can be much shorter than agreed on in the beginning, the agreed lead times are set in a contract and often on the save side to avoid contractual issues. Implementing lead time off setting in the proposed method is considered to be not optimal, because of the reasons described. Procurement employees often know from experience which materials can be replenished quickly and which ones not. For materials where it is not clear, communication with the supplier provides the best response to assess the feasibility of the proposed demand plan in terms of material requirement changes.

### 8.3.5 Including too much

Numerous additional parameters could have been included in the method, such as lead time (also described in section 8.3.4), stock levels, or replenishment cycles. The proposed method does not include these because the proposed method has the goal to assist in checking the impact of a proposed demand plan based on material requirement changes. This requires no additional parameters to be included. Employees might be eager to ask for extending the method with such parameters, only to use the method more and more as a stand-alone full MRP system that provides a future state of the supply chain, with current data. Although this seems desirable, this is not. Over time it will most likely resemble a second MRP system that is based on forecasted demand data, while its replenishment data, work floor data, product data, and other are not forecasts but current data. These will all change significantly in the future, creating an unrealistic future scenario that is then used by employees to judge the proposed demand plan. Instead employees should use the method to see what changes in material requirements are indicated and discuss these changes with suppliers on feasibility, when needed.

In addition, the method is kept simple to be more generalizable and easy to implement in other business situations, and time was a limiting factor to extend the method more and test it in a case environment.

## 8.4 Conclusion RQ 4

The original research question that is discussed in this section is the following:

- 4) *How can the changes in material requirement be calculated, based on a proposed demand plan and a previous demand situation, before an MRP run?*

Research question 4 aims to provide a method that can be used to solve the research problem.

The method proposed uses the same input and logic as an MRP system but it is reduced to only the crucial steps required to calculate material requirements and material requirement changes. The method uses 3 aspects as building blocks: BOM structures, a new and previous demand plan, and configuration percentages. The method consists of three consecutive phases. The first phase calculates the material requirements per time interval of 1 type of finished good. This step is performed for every unique finished good on the demand plan. The second phase sums up all the material requirements of the unique finished goods. The third phase calculates the absolute- and percentile changes between the old and new situation. The method can be used as a tool in a spreadsheet environment. It functions separately from an MRP system. The output data of a tool based on the proposed method can be used when assessing the feasibility of a proposed demand plan, by checking with suppliers if the material requirements are feasible or not.

## Part III: Case Study

### 9. Case study

In this chapter the third, fourth, and fifth step of the system development life cycle (SDLC) method will be evaluated, respectively implementation, verification and maintenance. The first section will cover the implementation step, the second section will cover the verification step and the third section will cover the maintenance step. The chapter concludes with answering research question 5.

#### 9.1 Implementation

The method proposed forms a set of rules on how the research problem can be solved. Implementing it varies from case to case due to case specific conditions. The proposed method has to be developed and/or programmed into a tool for it to be easy to use in business environments. For the case at Philips Healthcare MR the method was programmed with Visual Basic for Applications (VBA), with Microsoft Excel 2013 spreadsheet abilities to execute formulas within cells (see Appendix D for programming decisions, and Appendix E for the VBA code).

The tool created serves its purpose after the release of a proposed demand plan and prior to the S&OP meeting. In this meeting the proposed demand plan is accepted, rejected, or conditionally accepted. The time horizon between these two events is 3 to 5 working days long. In this time horizon the following steps have to be completed.

- Gather and load input data
- Execute tool
- Send-out output data to stakeholders
- Analyze material requirement data and check with suppliers
- Provide feedback for S&OP meeting

It is important that the tool is executed as soon as possible to allow enough time to analyze the output data. Once the tool is executed the remaining steps are manually performed by employees.

##### 9.1.1 Gather and load input data

The gathering of the input data is an important step. If the input data has errors, the output data will too. In the case of Philips Healthcare MR, the software application named *Every Angle* was used to extract the required data from the MRP system. *Every Angle* can download the BOM lists for each finished product and all vendor information specified per material code from the MRP system. The MRP system used at Philips Healthcare MR is SAP. It is important that prior to every run of the tool, new BOM lists are extracted to avoid errors in the output.

##### 9.1.2 Filter material requirement changes

To assess the materials in the output data, risk categorization can be a useful tool to improve the ability to filter out important information. Materials with a high risk should be identified quickly in order to correspond timely with the suppliers. Materials can be categorized in high, intermediate and low risk groups.

The categories are proposed as following:

- High risk materials: quantity increase or decrease  $\geq 20\%$  per planning cycle
- Intermediate risk materials: quantity increase or decrease  $> 10$  and  $< 20\%$  per planning cycle
- Low risk materials: quantity increase or decrease  $\leq 10\%$  per planning cycle

The categories can be marked with a color code that requires a certain level of attention from the assessing stakeholder. For example, Red indicates a large change and requires immediate attention, yellow indicates moderate changes and should be watched closely, and green changes fall within the limits of the flexibility of the supply chain. Table 16 depicts an example where color coding has been applied to an output data. This color coding concept improves the efficiency of analyzing the data by reducing the time required to find critical materials.

Table 16 - Color code marking example

% Changes																
Δ Jan	Δ Feb	Δ Mar	Δ Apr	Δ May	Δ Jun	Δ Jul	Δ Aug	Δ Sep	Δ Oct	Δ Nov	Δ Dec	Δ Tot	Δ Q1	Δ Q2	Δ Q3	Δ Q4
0%	0%	0%	0%	0%	0%	-36%	20%	29%	26%	38%	0%	77%	0%	0%	14%	64%
0%	0%	0%	0%	0%	0%	-32%	20%	16%	7%	19%	0%	29%	0%	0%	4%	25%
0%	0%	0%	0%	0%	0%	-37%	13%	43%	24%	63%	0%	105%	0%	0%	19%	86%
0%	0%	0%	0%	0%	0%	-22%	3%	17%	7%	14%	0%	19%	0%	0%	-2%	21%
0%	0%	0%	0%	-3%	-1%	-50%	47%	20%	18%	19%	0%	50%	0%	-4%	18%	37%
0%	0%	0%	0%	-2%	-1%	-40%	2%	55%	23%	30%	0%	67%	0%	-3%	17%	53%
0%	0%	0%	0%	-3%	-1%	-44%	25%	29%	19%	22%	0%	47%	0%	-4%	10%	41%
0%	0%	0%	0%	0%	0%	-38%	15%	43%	17%	41%	0%	78%	0%	0%	20%	59%
0%	0%	0%	0%	0%	0%	-37%	6%	57%	19%	41%	0%	87%	0%	0%	26%	60%
0%	0%	0%	0%	0%	0%	-22%	26%	4%	15%	22%	0%	44%	0%	0%	8%	37%
0%	0%	0%	0%	0%	0%	-28%	28%	7%	9%	21%	0%	36%	0%	0%	6%	29%
0%	0%	0%	0%	0%	0%	-25%	4%	15%	4%	9%	0%	7%	0%	0%	-6%	13%
0%	0%	0%	0%	0%	0%	-33%	22%	16%	8%	31%	0%	44%	0%	0%	5%	39%
0%	0%	0%	0%	0%	0%	-29%	28%	10%	9%	20%	0%	39%	0%	0%	10%	28%
0%	0%	0%	0%	0%	0%	-28%	35%	0%	14%	29%	0%	51%	0%	0%	7%	43%

## 9.2 Verification

The fourth step of the SDLC is to verify the design in a real case environment. The proposed method will be tested during the feasibility assessing in the months July and August 2015. The stakeholders will be provided with a presentation explaining the use of the method and tool prior to using them. As discussed in chapter 5, the method will be tested based on a set of propositions through interviews from different perspectives. The propositions will be discussed during a semi-structured interview with the aim to trigger the interviewee to think critically about the method, tool and propositions. The interview will start with an explanation of the goal of the interview, which is to determine the perceived value of the method, followed by discussing the 6 propositions. At the end of the discussion of each proposition the interviewee is asked to give a Likert scale response (Likert, 1932). The responses of all interviewees are presented in Table 17.

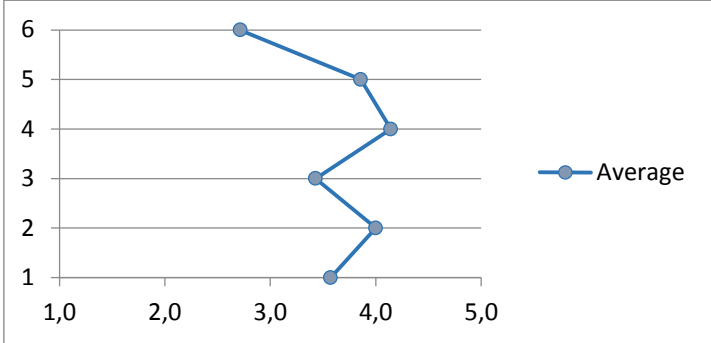
Table 17 - Interview responses

Propositions / Interviewees	1	2	3	4	5	6	7
1	4	4	4	3	4	2	4
2	4	4	4	4	5	3	4
3	3	3	4	3	3	4	4
4	4	5	5	4	3	4	4
5	4	4	4	4	3	4	4
6	3	2	3	2	3	3	3



In total 7 people were asked to participate in the interviews. Due to anonymity reasons no names of the interviewees or interview transcripts are included in this report. The average response for each proposition is presented in Table 18.

Table 18 - Average proposition response



In Table 18 the blue line shows the average outcome per proposition. We will now evaluate the outcomes per proposition based on the Likert scale results and feedback during the interviews.

*Proposition 1: The proposed method provides the correct material requirement information.* The outcome averages a 3.6, indicating that the information provided by the method is perceived to be above average. During interviews, it was suggested twice to extend the material information with material lead times to improve filtering out crucial increases that fall within lead times. In section 8.3 is discussed why this was not implemented in the method.

*Proposition 2: The output data variety positively influences the ability to assess the feasibility of a proposed demand plan.* The outcome averages at 4.0, indicating that the data provided is perceived to have a high positive contribution to assessing the feasibility of a proposed demand plan. During interviews all participants stated that the material requirements are leading for Philips Healthcare MR in judging the feasibility of a proposed demand plan. Especially oversee suppliers are critical.

*Proposition 3: The generated output of the proposed method is perceived accurate.* The outcome averages at 3.4, indicating that the data is perceived to be above average in accuracy. All interviewees stated that they could not know for sure if the data is accurate; a degree of trust was placed that the tool performs correctly. The output data can be checked with the MRP system after the proposed demand plan has been entered, but only 1 material at a time. Checking the whole output would be an incredibly time consuming and repetitive task.

*Proposition 4: The proposed method is perceived to be valid.* The outcome averages at 4.1, indicating that the data is perceived to be high in validity. Based on the interviews the output data accurately describes the real scenario a proposed demand plan will introduce, which was found to be helpful.

*Proposition 5: The proposed method is perceived reliable.* The outcome averages at 3.9, indicating that the data is perceived to be above average on reliability. The interviewees stated that when the tool would be executed correctly, the output data produced would be very consistent.

*Proposition 6: The data generated is correctly ordered to assist in the assessing process.* The outcome averages at 2.7, indicating that the data is perceived to be below average in correctness of data order. The interviewees provided feedback on improvements how the output data should be

formatted for it to be optimal in their working environments. Optimizations included the inclusion of additional material information and reordering the data output columns. The general issue with the output format is the large amount of columns that is necessary to display all the outputs, which usually requires two computer screens. When unnecessary columns or rows are deleted or collapsed, and when all columns are properly ordered, the perceived correctness of ordering should increase. However, for different stakeholders, different ordering scenarios are desirable.

The overall perceived value of the method scores a 3.6, indicating that the method provides an above average approach to solve the research problem correctly. Mainly the employees at the Philips Healthcare MR are satisfied with the output data that is provided to them. It provides them handles where there previously was no knowledge or data at all.

### 9.3 Maintenance

The maintenance of the method and tool after implementation falls outside the time frame and scope of this research. However it is part of the SDLC method used and will be briefly discussed. The maintenance to the method is relatively low. The proposed method can be updated when additional scientific insights are presented but no maintenance is required. The tool itself requires maintenance. Prior to every execution, the input data should be checked and updated when required. This is not a direct maintenance task, but rather falls in the execution phase. Updating BOM lists will be the most occurring and time consuming task. The tool itself functions properly once programmed but often when time passes, users request upgrades to the tool to improve efficiency. The upgrades can be categorized as maintenance and will be tasked to a programmer.

### 9.4 Conclusion RQ 5

The original research question 5 that is discussed in this section is the following:

- 5) *How adequate is the proposed method perceived, in an operational business environment, when assisting the assessing process of the feasibility of a proposed demand plan by stakeholders?*

Research question 5 aims to provide an evaluation of the method proposed based on perceived value. Perceived value is chosen because an accurate validity check would be very time consuming and will only confirm the use of correct programming. This is true because the method proposed uses the same input and logic as an MRP system, which can be considered as correct, but is reduced to only the crucial steps needed to require the desired result.

The perceived value was evaluated based on 6 propositions through interviews. The overall score concludes that the value of the method and tool are perceived to be above average, which indicates that the stakeholders/users are content with its functioning. More specifically, the method is perceived to have a high positive contribution in assisting the assessing of a proposed demand plan and its validity is also perceived to be high. The ordering of the output data is perceived to be just below satisfaction. Improvements to the output format are considered valuable and should be made as soon as possible. The correctness of data output, accuracy, and reliability of the method all score average. This means that the stakeholders are just content with it.

## 10. Conclusions & recommendations

The final chapter of this thesis includes the overall conclusions to the research project and its main question in section 10.1. Section 10.2.1 provides recommendations for Philips Healthcare MR. Section 10.2.2 provides possible subjects for further research.

### 10.1 Conclusions

The goal of this research has been to develop a method to assist in the assessing of the feasibility of a proposed demand plan in terms of material requirement changes, without entering the demand plan into an MRP system, for which the main research question was posed:

*How can changes in material requirement be determined before an MRP run, based on a proposed demand plan and an old demand plan, in order to assist in assessing the feasibility of that demand proposition?*

In traditional purchasing and logistics functions, MRP is one of the most vital functions of information technologies related to supply chain management. The benefits of an MRP system depend heavily on the availability of up-to-date data about the material needs. Accuracy has a vital role in a successful MRP system. Currently, insight on how to assess a proposed demand plan in high tech manufacturing environments with complex finished good structures on its material requirements is lacking. Philips Healthcare MR provided an opportunity to research this problem.

To our knowledge the literature provides solutions to the research problem that are not optimal. The solutions all suggest an increase in recalculation of the MRP system when new demand plans are released to obtain information about material requirement changes. The problem with the present solutions is that a full MRP run is required, which also requires to enter the proposed demand plan into the MRP system without knowing prior that it is feasible in terms of material requirements. If a plan is infeasible but entered into the MRP system the incorrect demand data can lead to incorrect material requirements or incorrect manufacturing schedules. In addition, the frequent updating of the MRP system, due to infeasibility of the demand plan, causes negative effects to the supply chain such as system nervousness. This research, in contrast, went beyond the scope of the present proposed solutions and extended the MRP logic with a method that would use MRP logic to perform a calculation to assist in assessing the feasibility of a proposed demand plan in terms of material requirements, prior to a full MRP run. The proposed method was developed into a tool and tested in the case environment at Philips Healthcare MR to study its perceived value by employees involved in the feasibility assessing process of a proposed demand plan, verifying its working. The proposed method allows calculating material requirement changes of a proposed demand plan, without using or influencing an MRP system, while requiring input data similar to that of an MRP system. Using the same input data as an MRP system makes the method suitable for implementation in environments where MRP systems are used. This makes it a wide spread solution to implement since MRP systems are used globally by manufacturing firms. Other high-tech manufacturers are likely to encounter the same business problem when a demand plan is proposed.

### 10.2 Recommendations

In this section recommendations are provided to the host of this research, Philips Healthcare MR, and further research recommendations are discussed.

### 10.2.1 Recommendations for Philips Healthcare MR

Philips Healthcare MR provided this research opportunity based on the difficulty of assessing the feasibility of a proposed demand plan properly. Based on the findings of this research we recommend to implement the proposed method of this research, and tool, into the process flow at Philips Healthcare MR. Implementing the method will allow for an improved feasibility check of a proposed demand plan, in terms of material requirements. The implementation requires the method and tool to be executed when a proposed demand plan is released, and to allow sufficient time, for the responsible department of material procurement, to assess the proposed demand plan with the output data of the method and tool. In addition, it is recommended that all users of the method and tool are trained to use the tool and understand its basic working. This avoids incorrect execution of the tool, misinterpretation of the output data, and increases the likelihood of identifying errors in the output data.

During this research, the logistical process of determining the material requirement changes of a proposed demand plan at Philips Healthcare MR was investigated. During this investigation, multiple consequences of the current process were identified, which are summarized in section 6.6. These consequences are not directly related to the research questions or problem, but can be useful for management when improving working efficiency.

Several consequences of the current method used at Philips Healthcare MR occur due to low forecast accuracy of the proposed demand plan. Therefore, the forecast accuracy of the proposed demand plan is considered an important point of improvement. Based on the knowledge obtained during this research about the forecasting method for the proposed demand plan, we expect that the method does not allow for an accurate resemblance of the reality. It is recommended to improve forecasting methods to better fit the reality.

Other consequences found display a low level of collaboration between different departments in the logistical information flow at Philips Healthcare MR. We found that employees have a tendency to not release responsibilities when information is passed down the line. We recommend that management takes actions to build a stronger sense of responsibility among employees that are linked to each other in terms of information flow.

### 10.2.2 Recommendations for further research

With respect to further research, several recommendations are proposed here. No distinction between recommendations in terms of importance is made.

#### *Method extension*

The proposed method can be extended to improve data accuracy and validity. However, extending it further and further will bring the method closer to a full MRP system, which is unsatisfactory because the goal is not to create a stand-alone MRP system next to the existing MRP system at manufacturing firms.

- Lead time: further research can be conducted to enhance the proposed method to incorporate the lead time off setting of materials. This will allow estimation of future order points in time and their desired quantity. This extra information can improve the assessing accuracy and the planning capabilities

- Work floor capacity: further research can be conducted to enhance the proposed method developed to incorporate the work floor capacity. With additional input information on routing times of manufacturing processes the sub-assemblies and exact order points of materials can be calculated.
- Standing replenishments: further research can be conducted to enhance the proposed method developed to incorporate replenishments that are stated in the MRP system. This will allow more accurate order point information for materials. This extension can be important for environments where materials are consumed with a relative very high speed.

#### *Scheduling fluctuations*

Also briefly mentioned in this thesis, is system nervousness introduced by frequent rescheduling of the MPS. Based on the MRP logic, MPS logic, and the researched process flow at Philips Healthcare MR we conclude that scheduling fluctuations are prone to occur in high-tech industries. The high-tech industry requires quick responsiveness to the market. When combining the desire to be responsive with complex manufacturing processes and complex product BOM structures, rescheduling increases. A schedule that fluctuates too much will introduce system nervousness into the supply chain, which is undesirable. Reducing system nervousness due to rescheduling, or reducing rescheduling in the high-tech industry, could be investigated in more detail.

#### *BOM complexity*

BOM structures in the high tech industry are often highly complex. The amount of unique materials that are found in complex products is relatively large. Such a large amount of unique materials makes it difficult to track what the impact of a demand change for specific finished goods has on the supply chain. If the BOM structure would be more understandable without the use of extensive software, employees would be in the position to assess demand changes more quickly and accurately. Investigated how the BOM structures complexity can be clarified for interpretation, or its complexity reduced, could be valuable for logistical operations in the high-tech industry.

## References

- Andrei, P. P. D., 2015. *Literature Review: Capacity feasibility analysis as an MRP-II extension at Philips Healthcare for MRI planning purposes*, Eindhoven: Technical University of Eindhoven.
- Andresen, M. & Domsch, M. E., 2007. *Working Unusual Hours and Its Relationship to Job Satisfaction: A Study of European Maritime Pilots*, New York: Springer Science + Business Media .
- Anon., 2015. *Object Management Group: Business Process Model and Notation*. [Online] Available at: <http://www.bpmn.org/>
- Blackburn, J. D., Kropp, D. H. & Millen, R. A., 1985. MRP System Nervousness: Causes and Cures. *Engineering Costs and Production Economics*, Volume 9, pp. 141-146.
- Blumberg, B., Cooper, D. R. & Schindler, P. S., 2008. *Business research methods*. s.l.:McGraw-Hill Higher Education.
- Carlson, R. C., Jucker, J. V. & Kropp, D. H., 1979. Less Nervous MRP Systems: A Dynamic Economic Lot-Sizing Approach. *Management Science and Engineering*, pp. 754-761.
- Cheng, P. W., 1997. *Effective Use of MRP-Type Computer Systems to Support Manufacturing*, Petersburg, VA-USA: Virginia Polytechnic Institute and State University.
- Clayton, T., 1997. Last points on Materials Requirements Planning (MRP). *New Zealand Manufacturer*, pp. 14-15.
- Correll, J. G., 1995. Reengineering the MRP II Environment. *IIE Solutions Vol.27*, pp. 24-27.
- Cox, F. J. & Blackstone, J. H., 2005. *APICS*. Chicago: Amer Production & Inventory.
- Feld, W. M., 2001. *Lean manufacturing: tools, techniques, and how to use them*. Florida: St. Lucie Press.
- Hopp, W. & Spearman, M., 2000. *Factory Physics: Foundations of Manufacturing Management 2nd Edition*. Irwin: McGraw Hill.
- Informer, S., 2015. *Every Angle Solution Suite*. [Online] Available at: <http://every-angle-solution-suite.software.informer.com/>
- Isaias, P. & Tomayess, I., 2015. *High Level Models and Methodologies for Information Systems*. 1th ed. New York, Heidelberg, Dordrecht, London: Springer.
- Klugman, K., 2014. *Why Material Requirements Planning is So Important?*. [Online] Available at: <http://blog.mrpeasy.com/material-requirements-planning-important/>
- Koh, S., Saad, S. & Jones, M., 2002. Uncertainty under MRP-planned manufacture: Review and Categorization. *International Journal of Production Research - Taylor & Francis*.
- Kranenburg, B. & Van Houtum, G. J., 2014. *Spare parts inventory control under system availability constraints*, Eindhoven: Springer.

- Kvale, S., 1996. *Interviews: An introduction to Qualitative Research Interviewing*. s.l.:Sage Publications.
- Langenkaemper, H., 2015. *Planning walk-in session* [Interview] (15 April 2015).
- Law, J., 2009. *A Dictionary of Business and Management*. 5 ed. ed. Oxford: Oxford University Press.
- Likert, R., 1932. A Technique for the Measurement of Attitudes. *Archives of Psychology*, Volume 140, pp. 1-55.
- McKay, D. J., 1993. MRP II concepts for process control engineers. *Elsevier ISA Transactions* 32, pp. 133-137.
- McKinsey & Company, 2008. The Challenges Ahead for Supply Chains: McKinsey Global Survey Results. *McKinsey Quarterly*.
- McNair, C. J. & Vangermeersch, R., 1998. *Total Capacity Management: Optimizing at the Operational, Tactical, and Strategic Levels*. Boca Raton: CRC Press.
- Minty, G., Masterson, G. & Towers, R., 1998. *Production Planning and Controlling: A Problem-Based Approach*. s.l.:Goodheart-Willcox Co..
- Mohan, R. P. & Ritzman, L. P., 1998. Planned Lead Times in Multistage Systems. *Decision Sciences - A Journal of the Decision Science Institute*, January, pp. Vol 29.163-191.
- Orlicky, J. A., 1973. Net Change Material Requirements Planning. *IBM Systems Journal*, p. Vol. 12 Is. 2 pg. 2.
- Pfohl, H. C. & Gomm, M., 2009. Supply Chain Finance: Optimizing Financial Flows in Supply Chains. *Logistics Research*, 1(3-4), pp. 149-161.
- Royce, W. W., 1970. *Managing the development of large software systems*. *Proceedings of the IEEE WESTCON*. Los Angeles, TRW, pp. 1-9.
- Selten, T. T., 2013. *Literature review on buffer management under uncertainty*. *Master Course Operations Management and Logistics*., Eindhoven: Technical University of Eindhoven: Technical University of Eindhoven.
- Simchi-Levi, D., Kaminsky, P. & Simchi-levi, E., 2000. *Designing and Managing the Supply Chain, USA*: McGraw-Hill.
- Steele, D. C., 1976. The nervous MRP system: How to do battle?. *Production and Inventory Management*, pp. 83-89.
- Toomey, J., 1996. *MRP II: Planning for Manufacturing Excellence*. s.l.:Springer US.
- Vollmann, T., Berry, W., Whybark, D. C. & Jacobs, F. R., 2005. *Manufacturing Planning and Control Systems for Supply Chain Management: The Definitive Guide for Professionals*. Sao Paulo: Bookman Companhia Ed.

Wutke, D. A., Blome, C., Froestl, K. & Henke, M., 2013. Managing the Innovation Adoption of Supply Chain Finance - Empirical Evidence From Six European Case Studies. *Journal of Business Logistics*, 34(2), pp. 148-166.



## Appendix A

### *SMI & SMOI materials*

SMI & SMOI respectively mean 'Supplier Managed Inventory' and 'Supplier Managed and Owned Inventory'. Both abbreviations are Philips's terminologies that refer to Vendor Managed Inventory. Vendor Managed Inventory (VMI) refers to inventories that are located at the consumer (Philips Healthcare MR), but are managed by the vendor (suppliers). The inventory management is based on demand input from the consumer, but final decisions are made by the vendor. This provides an environment where the vendor can regulate stock levels to its preference with demand data, and the consumer to have a high reliability of material availability. Typically VMI is a rolling demand forecast of 12 months ahead, based on product lead times. The difference between SMI & SMOI and VMI is that the SMI is financially owned by the consumer from the point of delivery, and SMOI remains owned by the vendor until consumed by the consumer.

### *One-time buy materials*

One-time buy materials are materials that are bought only once to fulfill a specific demand that is most likely not to be required again. With the fast technological development of high-tech business environments this is a common phenomenon. If a one-time buy material is required again a follow-up buy action can be initiated when the supplier still offers the material. However this is case specific.

## Appendix B

Materials with these inventory management protocols are labelled with an ABC (Activity-Based-Costing) priority classification. The ABC method indicates that inventory should be reviewed with the assistance of rating materials in the categories A, B, and C based on the following guidelines (Vollmann, et al., 2005).

- A-materials are goods whose annual consumption value is the highest. The top 70-80% of the annual consumption value of the company typically accounts for only 10-20% of total inventory materials.
- B-materials are the interclass materials, with a medium consumption value. 15-25% of annual consumption value typically accounts for 30% of total inventory materials.
- C-materials are materials with the lowest consumption value. The lower 5% of the annual consumption value typically accounts for 50% of total inventory materials.

The annual consumption value is calculated with the formula:

$$\text{Annual consumption} = \text{Annual demand} * \text{Cost per item}$$

For each material category an upper- and lower limit of stock levels is set for the supplier. This means that the supplier should maintain stock levels within these boundaries. The upper- and lower stock limits are pre-defined for each material category. In table B1 an overview is given on the rules for stock limits at Philips Healthcare MR, describing several material categories and their stock limits.

The A and B categories have further categorization based on their variation coefficient. Distinction is made between materials with a variance larger or smaller than 0.5. The distinction of variance is based on demand behavior. The coefficient of variation is calculated by dividing the standard deviation of a material by the mean of the average demand. Demand is taken for the last 12 months. This can be formalized as following.

$$\text{Coefficient of variation} = \frac{\sqrt{\frac{((D - D_1)^2 + \dots + (D - D_n)^2)}{n - 1}}}{\frac{(D_1 + \dots + D_n)}{n}}$$

where

$n$  = specific material

$D_n$  = demand for material  $n$  over time period  $t$

Within each sub-category, materials are again sub-categorized based on lead times with short-, middle-, and long- lead times. For each lead time category the stock levels are set as weeks of demand. This means that the lower- and upper stock limits are expressed as a number of weeks' worth of demand that should be in held as inventory by the vendor. For category C the process is simpler, the distinction is made based on material value. Material with a value higher than 25 euro have lower- and upper stock limits of 4 to 8 weeks, whereas materials with a value lower than 25

euro have lower- and upper stock limits of 9 to 18 weeks. Table B1 provides an overview of the stock limit rules.

Table B1 - ABC stock limits

ABC	Variation Coefficient			Lead time Range				LSL (weeks demand)	USL (weeks demand)	
A, B	<	0,5		Between	0	and	2	weeks	1	3
				Between	3	and	9	weeks	1	3
				Between	10	and	999	weeks	1,5	3,5
A, B	>	0,5		Between	0	and	2	weeks	1,5	3,5
				Between	3	and	9	weeks	2	4
				Between	10	and	999	weeks	3	5
C	>	25	EUR						4	8
	<	25	EUR						9	18

On the occasion the upper stock limits and their corresponding weeks of inventory still results in an OOS situation, the procurement department can choose to increase inventory momentarily with an extra replenishment or by permanently setting the upper stock limit higher if reoccurrences of the OOS is to be expected. The other way around the stock situation can be lowered by decreasing the upper- and lower stock limits when decreased demand is expected. The changes to these stock limits are infrequent and are subject to contract agreements between the supplier and Philips Healthcare MR. These contracts were not accessible for this research.

## Appendix C

The method will be tested in a case environment at Philips Healthcare MR covering the material requirements for MRI devices. The information provided in this appendix serves as additional case information to address the company's problem and contributes to the understanding of programming decisions in forming a tool based on the proposed method.

### *Quantity driven*

The process of checking if the proposed demand plan is feasible remains a human task. The data generated may provide new logistical insight but it still depends on supplier's flexibility if a proposed demand plan can be met or not. Because of the importance of supplier flexibility, the quantities of material requirements play a significant role in whether or not a proposed demand plan is feasible. For suppliers it is almost exclusively important to know the quantity per time horizon, such that the suppliers can anticipate and adjust production accordingly. Because of this the method and tool are focused on material quantities and changes in material quantities per time interval.

### *Material identification*

When a large number of different materials are in the supply chain, a clear identification system is required to provide clear material information. With over 4000 SKU's for the assembly of MRI devices at Philips Healthcare MR, using only material names or descriptions may not be sufficient. Philips Healthcare MR uses a system referred to as 12NC which stands for 12 digit Numerical Code. The system identifies every material with a 12 digit numerical value. Within these codes additional information normally is included. For example materials that start with 4522 normally refer to in-house production sub-assemblies and 9896 materials are higher level procurement materials. However, this is an indication and can vary due to 12NC numbers being reassigned randomly when a materials leaves the supply chain and a new materials requires an available 12 NC code. In practice it does provide an extra handle to quickly identify certain material groups in lists.

### *Input data*

The MRP system used at Philips is *SAP*. *SAP* does not have the ability to extract data easily. To assist with data acquisition the software package *Every Angle* is used. *Every Angle* is a *SAP* add-on used for interpretation and extraction of *SAP* data for business professionals (Informer, 2015). Within *Every Angle*, users can construct data extraction sets which are referred to as *Angles*. The process to construct these *Angles* will not be discussed as the structure of an *Angle* is related to how *SAP* is arranged internally by the manufacturer. For this thesis two *Angles* are constructed to provide the tool with the required input data.

The first *Angle* generates a complete material list of an individual product, also known as the BOM list. The information specifications per material are extended with additional logistical parameters that are relevant for the assessing process, which are the following:

- Current stock level
  - Expressed as an integer number of units
- Material price
  - Price per material
  - Expressed in the currency used by the company
- Total stock value

- Expressed in the currency used by the company
- Multiplication of stock value and current stock level
- Material lead time
  - Expressed as an integer number of days
- Procurement type
  - Company specific terms in which materials are categorized
- Purchasing group
  - Either a group or person that holds responsibility or purchasing for specific material
- Bulk
  - Yes/No value
- Inventory management protocol
  - ERP protocol used to manage inventory.

In addition to these logistical parameters, there is the ‘higher level material’. The higher level material is important of the explosion of the configuration percentage. Table C1 depicts a partial output from the *Angle* extracting BOM lists to given an indication of the angle build. The price, stock, and lead times columns have fictional values for confidential purposes.

**Table C1 - BOM list example Every Angle**

Material	Description	Q	Lvl	ABC	Stock	q	Price	Stock	Lead time	Procurement type	PG	Bulk	MRP Type (Component on Pla	Material	Description (Material)
989603020452	GRADIENT SET DUAL MODE	100	001	A	(Si	18,00	3244,73	58.405,14	EUR	300 Days	E (In-house production)	No	M0 (MPS, fixing type -0)	P781377001	PLANNING BOM FOR 781377
989603020411	RF VENT PIPE FEEDTHROUGH 3.0T	100	001	B	(M	12,00	635,32	7.623,84	EUR	84 Days	F (External procure	014 ( No	Y2 (SNC: SOI (-Plan;+SDreqs))	P781377001	PLANNING BOM FOR 781377
989603022791	SERVICE PLATFORM WA MAGNET	100	001	B	(M	32,00	476,00	15.232,00	EUR	20 Days	F (External procure	004 ( No	M0 (MPS, fixing type -0)	P781377001	PLANNING BOM FOR 781377
989603022901	QUENCH PIPE WA 3.0T	100	001	A	(Si	21,00	1994,63	41.887,23	EUR	42 Days	F (External procure	014 ( No	Y2 (SNC: SOI (-Plan;+SDreqs))	P781377001	PLANNING BOM FOR 781377
989603111873	INGENIA HEADSET	100	001	B	(M	73,00	850,05	62.053,65	EUR	45 Days	F (External procure	060 ( No	Z1 (Noct: SMI (-Plan;+SDreqs))	P781377001	PLANNING BOM FOR 781377
989603022491	GRAD COIL KIT NX1164 & AZ8104	100	001	B	(M	123,00	36,00	4.428,00	EUR	30 Days	F (External procure	026 ( No	PD (MRP)	P781377001	PLANNING BOM FOR 781377
989603019018	DSTREAM INTERFACE-3.0T-IRF	100	001	A	(Si	8,00	4357,62	34.860,96	EUR	78 Days	F (External procure	035 ( No	Y2 (SNC: SOI (-Plan;+SDreqs))	P781377001	PLANNING BOM FOR 781377
989603026121	SFB WA 3.0T PV	100	001	A	(Si	10,00	3924,95	27.474,65	EUR	84 Days	F (External procure	014 ( No	Y2 (SNC: SOI (-Plan;+SDreqs))	P781377001	PLANNING BOM FOR 781377
989603019156	PATIENT SUPPORT-3.0T-IRF	100	001			27,00	32064,05	705.409,10	EUR	0 Days	E (In-house produc	L92 (I No	M1 (MPS, fixing type -1)	P781377001	PLANNING BOM FOR 781377
989603027761	wBTU PPU + RESP MODULE	100	001			15,00	1052,67	15.790,05	EUR	0 Days	E (In-house produc	L92 (I No	M0 (MPS, fixing type -0)	P781377001	PLANNING BOM FOR 781377
989603027771	wBTU VCG MODULE	100	001			15,00	1052,67	15.790,05	EUR	0 Days	E (In-house produc	L92 (I No	PD (MRP)	P781377001	PLANNING BOM FOR 781377
989603208031	dS HeadNeck 3.0T	100	001	A	(Si	21,00	11818,47	189.095,52	EUR	45 Days	F (External procure	060 ( No	Z1 (Noct: SMI (-Plan;+SDreqs))	P781377001	PLANNING BOM FOR 781377
989603208011	dS BASE 3.0T	100	001	A	(Si	23,00	14560,58	145.605,80	EUR	45 Days	F (External procure	060 ( No	Z1 (Noct: SMI (-Plan;+SDreqs))	P781377001	PLANNING BOM FOR 781377
989603027523	INSTALLATION PARTS WA 3.0T	100	001			6,00	8005,65	48.033,90	EUR	0 Days	E (In-house produc	L92 (I No	M0 (MPS, fixing type -0)	P781377001	PLANNING BOM FOR 781377
989603023473	GMDU 50Hz 400V	100	001			83,00	1393,81	114.292,42	EUR	133 Days	F (External procure	081 ( No	Y2 (SNC: SOI (-Plan;+SDreqs))	P781377001	PLANNING BOM FOR 781377
989710007922	LCC2B SHI 50Hz	100	001			21,00	6531,00	124.089,00	EUR	90 Days	F (External procure	014 ( No	Y2 (SNC: SOI (-Plan;+SDreqs))	P781377001	PLANNING BOM FOR 781377

The second *Angle* required for the method is a list of each material and its corresponding supplier. The *Angle* generates a list of suppliers with their corresponding supplier code for each unique material. Table C2 depicts a partial output of the supplier list.

**Table C2 - Supplier list example Every Angle**

Material	Description (Material)	Nr	Name and description (Standard	MRP Type
989601041313	FLASHLITE FOR SURGERY VERADIUS	111329	111329 (Philips Electronics Nederland B	Z7 (PD (+Plan;-SDreqs))
242201606107	GLANDNUT BRNI PG7 420/7	111612	111612 (Philips Enabling Techn. Group)	Z7 (PD (+Plan;-SDreqs))
251102602026	DIST. PIECE INS. OUTS. THRD M3X10	111612	111612 (Philips Enabling Techn. Group)	V3 (Manual ROP with adc
252218721093	SCREW C_SUNK HD SLOT A4 M4X16	111612	111612 (Philips Enabling Techn. Group)	ND (No planning)
252220304064	SCREW C_SUNK HD TORX M6X30	111612	111612 (Philips Enabling Techn. Group)	Z7 (PD (+Plan;-SDreqs))
252264208132	FELSB MS AG 3X0.3X4	111612	111612 (Philips Enabling Techn. Group)	ND (No planning)
262211503371	DRUKVEER D13300	111612	111612 (Philips Enabling Techn. Group)	PD (MRP)
452209006371	PRECU W CSW3001 25/43/25	111612	111612 (Philips Enabling Techn. Group)	PD (MRP)
452209006381	PRECU W CSW3001 25/55/25	111612	111612 (Philips Enabling Techn. Group)	PD (MRP)
452209006391	PRECU W CSW3001 25/60/25	111612	111612 (Philips Enabling Techn. Group)	PD (MRP)
452209006401	PRECU W CSW3001 25/154/25	111612	111612 (Philips Enabling Techn. Group)	PD (MRP)
452209006411	PRECU W CSW3001 25/167/25	111612	111612 (Philips Enabling Techn. Group)	PD (MRP)
452210253142	TEKSTPL 21962 21,9X15,2	111612	111612 (Philips Enabling Techn. Group)	PD (MRP)
452216318544	BEUGEL DSC ENCODER	111613	111613 (VDL ETG)	PD (MRP)
863900001185	COLOR MON 17A580BQ/20C	114605	114605 (NIET GEBR.ZIE 678411)	PD (MRP)
459800144591	TS parts module	119259	119259 (PHILIPS MEDICAL SYSTEMS NED	ND (No planning)

All generated outputs from *Every Angle* can be easily transported to a excel sheet with the supported plug-in from *Every Angle*. These results in datasheets in excel as input for the method.

### *Usability*

It is of importance that the developed tool is easy to use. The end-users of it will in general be operational employees that do not have extensive programming knowledge. Favored is an implementation with Microsoft Office Excel, which is widely used throughout most offices. To improve usability further, the error sensitivity of the method and tool should be low. Manual inputs are unavoidable with the use of excel but have to be reduced to a minimum and if so be guided as much as possible. The readability of the output data is required to be simple. The data should be clearly formatted and easy to understand. Overviews that provide quick interpretation of demand changes should be provided.

### *Information clarity*

The output data that the method and tool generate is interpreted by employees of the material procurement department. The data comprises many data lines. In order for the data to be understandable for the human eye, a reduction in volume is necessary. Because all the data is equally important for the main purpose of this research, judging the feasibility of the proposed demand plan, it cannot be decreased in volume by deleting data entries. The data volume should be reduced smartly. Proposed here is the use of a classification system that categorizes materials in certain groups. For example, a color coding classification of the output data can be made as described in this research. Each category includes materials that have a different influence on the supply chain. With this method the most crucial materials, in terms of feasibility, can be clustered. When only the most crucial materials are presented in an overview, employees can address their feasibility more easily.

## Appendix D

In this section the programming logic of the tool is discussed. To provide a reproducible tool the programming will be evaluated in a step-by-step manner.

*Note: due to usability requirements of the case the tool was created using VBA macros. The setup of the proposed method can be programmed in any basic programming language.*

The tool is programmed step-by-step based on the logic of the proposed method and requirements. The tool follows the following programming steps:

- Setup frame of input
- Define variables
  - Workbook
  - Worksheet
  - Material name
  - Row look-up
  - Leading data range (Material number)
  - Integers
- Single BOM handling loop
  - Demand format
  - List handling
- Clear calculation sheets
- Rate of occurrence explosion
  - Filter
  - Look-up rate of occurrence
- Calculate output (per BOM)
  - Calculate
  - Create output sheet
- Create Master list
  - Copy single BOM outputs
  - Remove duplicates
  - Link additional information
  - Apply format
- Delete unnecessary data
- Save output to new file
- Error handler
  - Destination error
  - Input error

Each step will be evaluated to provide a basis for reproduction in other environments that use MRP logic. The explanation is setup to comprise of 1 workbook with multiple calculation sheets.

### *Setup frame of input*

As mentioned before, the method is built upon standard input data from an MRP system. The input components are the following:

- BOM Lists
- Supplier list
- Proposed demand plan
- Previous proposed demand plan
- Configuration percentages

A visual framework has to be created for the end-users to assist in easy usability. By this we mean that all inputs should be guided and restricted as much as possible to avoid errors. For example the proposed demand plans should be easy copy & paste actions. The BOM lists from the MRP system can be imported as raw MRP data lists in separate sheets in order to be read and copied when needed by the program. Overall 3 different types of sheets are made: (1) BOM list sheets, (2) Supplier sheet, and (3) demand comparison sheets. Depending on how many BOM structures will be included the number of total sheets may vary.

#### *Defining variables*

Often at the beginning of a program, variables are defined as references that are used throughout the code. The variables for the tool include references to:

- Which workbook to select based on workbook name
- Which sheet to select based on sheet name
- Which row number to select as long Integer
- Name as string for copying names
- 2 variables for calculation needs as integer

Defining these variables provides a base for the rest of the tool.

#### *Single BOM handling loop*

The number of finished goods included in the input, determines the amount of BOM structures that need to be exploded and calculated. BOM list can become relatively long with large amounts of data included. To reduce memory use and prolonged calculation times due to such large amounts of data, the BOM lists are handled one at a time in loop-like manner. The output is saved to a new sheet, allowing the old BOM lists and calculated value to be deleted to reduce file size. Programming a loop to handle each BOM one by one is strongly recommended to reduce processing requirements and processing time. Using a list that defines all the BOM structures allows the program to look up which BOM list is next in line to handle. A proposed demand plan provides various finished goods which directly translate to which BOM structures need to be handled and copied to the handling list. The list can be setup as a range, where the next BOM can be handled when the current BOM is finished.

This formalization dictates to look up the sheet with the name equal to the name found in the range of the handling list. The correct BOM lists sheet should be activated and used for calculations. After calculation of 1 BOM, the program can use the handling list to go to row  $r+1$ , where  $r$  is the current BOM used to calculate and loops this until the handling list hits an empty cell.

Before the program begins calculations, it is important to clear calculation sheets to avoid any errors in data usage.



### *Configuration percentage explosion*

The BOM structures come in list format where each material and its higher level material or components should be indexed. To explode the configuration percentage to all levels of the BOM the higher level material configuration percentages is looked up. By ordering the BOM list in descending order of BOM level, a program can use a 'look-up' formula to search for the configuration percentage of a materials higher level material.

Example: a material in the 7<sup>th</sup> level of the BOM can look-up its configuration percentage value by starting a search top down from its own position for the corresponding higher level material and its configuration percentage. When not ordered in descending order of BOM level a material that is used on multiple BOM levels can look up the wrong higher level configuration percentage even though it found the correct material based on 12NC

The calculation procedures of the spreadsheet tool can be programmed in VBA or manually made in a spreadsheet. For the tool made for Philips Healthcare MR, a combination of VBA and manual formula input was used. The most important formulas will now be evaluated.

### *Configuration percentage explosion and requirement calculation*

For this step the following formula provides an example.

```
IFNA(IF($D3="001";($C3/100)*VLOOKUP(ZMATS!$E$2;'INPUTShipmentplan'!$B:$T;3;FALSE);SU  
MIF($A3:A$14824;$N3;$T3:T$14824)*$C3);0)
```

This formula shows the following steps: for first level components: the percentage is copied, multiplied with the quantity specified in the BOM, and multiplied by the proposed demand of finished good. This results in the material requirements for all first level components.

All materials in the second level or lower look up the material requirements of their higher level material and multiply it by the quantity required to produce the sub-assembly in the BOM.

### *Copy away calculated BOM*

The BOM sheet is calculated based on formulas. These formulas are normally not integrated in the code but are located in the cells of the workbook. An example of such a formula is given in the previous paragraph. After calculating the output data, the data has to be copied away to a new sheet and the old calculations can be deleted to continue with the next BOM lists. In our tool we opted to copy away the data as values to avoid formulas being copied that can introduce faulty data. Copying away large amount of values from formulas that are nested multiple times can be difficult for a spreadsheet program such as excel to perform. We suggest that the copying phase takes place in small steps, copying small amount of columns per step.

### *Master List*

After the material requirements for each individual BOM list are calculated, the summation process follows. The output data from all the calculation sheets should be copied into one sheet, which results in a relatively long list with many duplicate materials. The next step is to sum all the duplicate material requirements for individual material codes for each time interval.

### *Delete unnecessary data*

The last step of the program should be deleting all data that is not relevant for the output. Earlier in the program the BOM lists were deleted after calculation. Another source of excess data is the empty

rows of data at the end of a sheet. In the calculation sheet that removed duplicates empty rows are often present. Deleting empty rows on all output sheets reduces the output file size significantly.

#### *Error handling*

When code is written errors often occur as a result when details are being overlooked. Covering every aspect of an environment into a programmed model is a skilled practice. For this case 2 specific occurring errors in relation to usability have been coded in. The first possible error is the missing of a BOM list. Every BOM list has to be manually loaded as input which makes it prone for human error. If a BOM list is missing, the program will give notice of the specific BOM list missing. This allows the user to correct the error and re-run the program.

The second error is when the destination path where the output data is saved is not accessible. The program will most likely be stored on shared hard drives within a company's IT infrastructure. If the output locations path is not accessible, an error notification should appear.

#### *Improve calculation time*

The calculation times of a tool with the proposed method and the use of many BOM lists can be relatively high. Also computers require an extensive amount of memory to perform the fast amount of calculations. To reduce the required time the tool uses to calculate, some programming steps can be included. Reducing the amount of data that the tool needs to calculate, copy, paste, or alter per iteration or step can reduce the calculation times.

## Appendix E

This Appendix includes the VBA coding used to implement the method at Philips Healthcare MR. The displaying of this code, together with Appendix D, serves as an example on how the method can be implemented in a high-tech operational environment where spreadsheet applications are used.

```
Sub CalculateSheets()  
    Dim wb As Workbook  
    Dim ws As Worksheet  
    Dim name As String  
    Dim FindRowNumber As Long  
    Dim NewFile As String  
    Dim x As Integer  
    Dim p As Integer  
    Dim StartTime As Double  
    Dim EndTime As Double  
  
    StartTime = Timer  
  
    'Declare wb as activeworkbook  
    Set wb = ActiveWorkbook  
  
    x = Sheets("ZMATS").Range("B2").End(xlDown).Row  
  
    'Declaring output filepath and filename  
  
    NewFile = "C:\Users\310118601\Desktop\development\ShipmentPlan_Test_01"  
    'NewFile = "\\dept2\q-mrfalg\Global Ops MR\12_Planning\02_Planning\03_Shipment Plan  
Translator\ShipmentPlanTranslation_" & Format(Now, "yyyy-mm-dd")  
  
    Application.ScreenUpdating = False  
    Application.Calculation = xlManual  
  
On Error GoTo ErrorHandler2  
  
    Do  
        wb.Sheets("ZMATS").Select  
        name = Range("B" & 2 + r)  
        r = r + 1  
        Set ws = ActiveWorkbook.Sheets(name)  
        ws.Select  
        wb.Sheets("ZMATS").Select  
        Range("B" & 2 + r).Select  
        Loop Until IsEmpty(ActiveCell.Offset())  
  
    r = 0  
  
On Error GoTo 0  
  
    'Enables ErrorHandler if "NewFile" location is not accessible  
On Error GoTo ErrorHandler
```

```

'Saves new workbook as "Newfile"
ActiveWorkbook.SaveAs Filename:=NewFile, _
    FileFormat:=52, _
    Password:="", _
    WriteResPassword:="", _
    ReadOnlyRecommended:=False, _
    CreateBackup:=False

'Resets ErrorHandler to default mode
On Error GoTo 0

Sheets("Calcsheet2").Select
Range("A3:A1000000").Select
Selection.EntireRow.Delete
Range("A3").Select
ActiveWorkbook.Save

p = 0

Do

wb.Sheets("CalcSheet1").Select
If ActiveSheet.AutoFilterMode = True Then ActiveSheet.AutoFilterMode = False
Range("A3:O100000").ClearContents
Range("Q4:BT100000").ClearContents

wb.Sheets("ZMATS").Select
name = Range("B" & 2 + r)
Range("E2").Value = name
r = r + 1
Set ws = ActiveWorkbook.Sheets(name)
ws.Select

Application.StatusBar = "Progress: " & p & " of " & x & ": " & Format(p / x, "Percent") & " Preparing
ZMAT " & name
DoEvents

With wb.Sheets(name)
    Set FindRow = .Range("A:A").Find(What:="Component .", LookIn:=xlValues)
End With

i = FindRow.Row

Range("A" & i + 1).Select
Range(Selection, ActiveCell.SpecialCells(xlLastCell)).Select

Selection.Copy Destination:=Sheets("CalcSheet1").Range("A3")

wb.Sheets("CalcSheet1").Select

On Error Resume Next

```

```
ActiveWorkbook.Worksheets("CalcSheet1").Sort.SortFields.Clear  
On Error GoTo 0
```

```
With ActiveSheet
```

```
    n = .Cells(.Rows.Count, "A").End(xlUp).Row
```

```
End With
```

```
ActiveWorkbook.Worksheets("CalcSheet1").Sort.SortFields.Add Key:=Range_  
    ("D3:D" & n), SortOn:=xlSortOnValues, Order:=xlDescending, DataOption:=_  
    xlSortTextAsNumbers
```

```
ActiveWorkbook.Worksheets("CalcSheet1").Sort.SortFields.Add Key:=Range_  
    ("A3:A" & n), SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=_  
    xlSortTextAsNumbers
```

```
With ActiveWorkbook.Worksheets("CalcSheet1").Sort
```

```
    .SetRange Range("A2:O" & n)
```

```
    .Header = xlYes
```

```
    .MatchCase = False
```

```
    .Orientation = xlTopToBottom
```

```
    .SortMethod = xlPinYin
```

```
    .Apply
```

```
End With
```

```
Sheets("CalcSheet1").Copy After:=Sheets(ThisWorkbook.Sheets.Count)
```

```
Sheets("CalcSheet1 (2)").name = "C_" & name
```

```
Application.DisplayAlerts = False
```

```
Sheets(name).Delete
```

```
Application.DisplayAlerts = True
```

```
'//////////
```

```
Application.EnableEvents = False
```

```
Range("Q3").Copy
```

```
Range("Q4:Q" & n).PasteSpecial
```

```
Application.CutCopyMode = False
```

```
ActiveSheet.Calculate
```

```
Range("Q3:Q" & n).Select
```

```
Selection = Selection.Value
```

```
Range("R3:AJ3").Copy
```

```
Range("R4:AJ" & n).PasteSpecial
```

```
Application.CutCopyMode = False
```

```
ActiveSheet.Calculate
```

```
Range("R3:AJ" & n).Select
```

```
Selection = Selection.Value
```

```
'//////////
```

*'Range("Q3:BT" & n).Value = Range("Q3:BT" & n).Value*

*'ActiveSheet.UsedRange.Copy  
'ActiveSheet.UsedRange.PasteSpecial xlPasteValues  
'Application.CutCopyMode = False  
'ActiveSheet.Select  
'Cells.Select  
'Selection.Copy  
'Selection.PasteSpecial Paste:=xlPasteValues  
'Application.CutCopyMode = False*

*'Range("Q3:BT" & n).Select  
'Application.EnableEvents = False  
'Selection = Selection.Value  
'Application.EnableEvents = True*

*'////////////////////*

*Range("AL3:BT3").Copy  
Range("AL4:BT" & n).PasteSpecial  
Application.CutCopyMode = False*

*ActiveSheet.Calculate*

*Range("AL3:BT" & n).Select  
Application.EnableEvents = False  
Selection = Selection.Value*

*Application.EnableEvents = True*

*'////////////////////*

*Range("AL2:BT2").Select  
Selection.AutoFilter*

*Range("A3").Select  
Range(Selection, ActiveCell.SpecialCells(xlLastCell)).Select*

*With Sheets("CalcSheet2")  
    n = .Cells(.Rows.Count, "A").End(xlUp).Row  
End With*

*Selection.Copy Destination:=Sheets("CalcSheet2").Range("A" & n + 1)*

*wb.Sheets("ZMATS").Select*

*Range("B" & 2 + r).Select*

*p = p + 1  
Loop Until IsEmpty(ActiveCell.Offset())*

*Application.StatusBar = "Progress: " & p & " of " & x & ": " & Format(p / x, "Percent") & "  
Calculating Mastersheet, this may take a few minutes.."*

*DoEvents*

*r = 0*

*Sheets("CalcTotal").Select*

*With Sheets("CalcSheet2")*

*n = .Cells(.Rows.Count, "A").End(xlUp).Row*

*End With*

*Sheets("CalcTotal").Range("Q4:CL100000").ClearContents*

*Sheets("CalcTotal").Range("A3:O100000").ClearContents*

*Sheets("CalcSheet2").Range("A3:O" & n).Copy Destination:=Sheets("CalcTotal").Range("A3")*

*Sheets("CalcTotal").Range("\$A\$2:\$O" & n).RemoveDuplicates Columns:=1, Header:=xlYes*

*With Sheets("CalcTotal")*

*n = .Cells(.Rows.Count, "A").End(xlUp).Row*

*End With*

*Sheets("CalcTotal").Range("Q3:FX3").Copy Destination:=Sheets("CalcTotal").Range("Q4:FX" & n)*

*ActiveSheet.Calculate*

*Sheets("CalcTotal").Copy After:=Sheets("CalcTotal")*

*Sheets("CalcTotal (2)").name = "MasterSheet"*

*Sheets("MasterSheet").Select*

*Application.EnableEvents = False*

*Range("Q3:Q" & n).Select*

*Selection = Selection.Value*

*Range("R3:AJ" & n).Select*

*Selection = Selection.Value*

*Range("AL3:BB" & n).Select*

*Selection = Selection.Value*

*Range("BD3:BT" & n).Select*

*Selection = Selection.Value*

*Range("BV3:CL" & n).Select*

*Selection = Selection.Value*

*Range("CN3:DD" & n).Select*

*Selection = Selection.Value*

*Range("DF3:DV" & n).Select*

*Selection = Selection.Value*

*Range("DX3:EN" & n).Select*

*Selection = Selection.Value*

*Range("EP3:FF" & n).Select*

*Selection = Selection.Value*

*Range("FH3:FX" & n).Select*

*Selection = Selection.Value*

*Application.EnableEvents = True*

*'Range("Q3:FX" & n).Value = Range("Q3:FX" & n).Value*

*'////////////////////////////////////*

*Sheets("MasterSheet").Range("C2:C" & n).ClearContents  
Columns(14).EntireColumn.Delete  
Columns(14).EntireColumn.Delete  
Columns(15).EntireColumn.Delete  
Range("C:D").EntireColumn.Insert*

*Sheets("MasterSheet").Range("M2:M" & n).Copy Destination:=Sheets("MasterSheet").Range("C2")  
Sheets("MasterSheet").Range("Q2:R" & n).Copy Destination:=Sheets("MasterSheet").Range("D2")*

*Columns(13).EntireColumn.Delete  
Columns(16).EntireColumn.Delete  
Columns(16).EntireColumn.Delete*

*'////////////////////////////////////*

*Range("A2:FT2").Select  
Selection.AutoFilter*

*Application.DisplayAlerts = False  
Sheets("INPUT Shipmentplan").Delete  
Sheets("INPUT Vendor-Material").Delete  
Sheets("CalcSheet1").Delete  
Sheets("CalcSheet2").Delete  
Sheets("CalcTotal").Delete*

*'Do  
'wb.Sheets("ZMATS").Select  
'name = Range("B" & 2 + r)  
'r = r + 1  
'Set ws = ActiveWorkbook.Sheets(name)  
'ws.Delete  
'wb.Sheets("ZMATS").Select  
'Range("B" & 2 + r).Select  
'Loop Until IsEmpty(ActiveCell.Offset())*

*Sheets("ZMATS").Delete*

*p = p + 1*

*Application.StatusBar = "Progress: " & p & " of " & x & ": " & Format(p / x, "Percent") & " Almost  
finished.."  
DoEvents*

*Application.StatusBar = False  
Application.DisplayAlerts = True  
Application.ScreenUpdating = True*



*ActiveWorkbook.Save*

*EndTime = Timer - StartTime*

*MsgBox "Shipment plan is translated, enjoy! " & Format(Round(EndTime, 0), "00:00:00"), vbOKOnly, "Finished"*

*Exit Sub*

*'ErrorHandler gives a message when the destination filepath is not accessible*

*ErrorHandler:*

*MsgBox "The destination filepath can not be found or accessed," & vbNewLine \_  
& "please check if the filepath below is accessible:" & vbNewLine \_  
& vbNewLine \_  
& NewFile, vbExclamation, "Filepath can not be found.."*

*Application.ScreenUpdating = True*

*Exit Sub*

*'ErrorHandler2 gives a message when one of the inputsheets is not available*

*ErrorHandler2:*

*MsgBox "One of the input sheets cannot be found," & vbNewLine \_  
& "please check if the inputsheet below is available:" & vbNewLine \_  
& vbNewLine \_  
& name, vbExclamation, "Inputsheet is not available"*

*Application.ScreenUpdating = True*

*End Sub*