Nottingham Trent University

Doctor of Business Administration
Document 5

Interpreting and applying Demand Driven MRP
A case study

by

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A thesis submitted in partial fulfilment of the requirements of Nottingham Trent University for the degree of Doctor of Business Administration

7th June 2015

Copyright Statement

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0 Abstract

Purpose – The purpose of this research is to evaluate Demand Driven Material Requirements Planning (DDMRP) in the context of improving the performance of a printing ink manufacturing company. The main issues the company is facing include poor due-date performance, stock levels not corresponding to the actual market needs and overall system instability leading to inefficiencies. The research evaluates the assumption underpinning Material Requirements Planning (MRP) and the Theory of Constraints (TOC) before considering their integration to meet the requirements of this company, with particular reference to a recent development entitled DDMRP.

Design/methodology/approach – Case research was used to establish the underlying issues through semi-structured interviews, observation, Enterprise Resource Planning (ERP) data and questionnaires. This analysis was then compared with the assumption underpinning generic TOC solutions before conducting a simulated evaluation to compare past ERP decision making with DDMRP.

Findings – DDMRP is shown to embody the concepts of buffer aggregation and buffer management within the context of dependent demand planning, effectively integrating MRP and TOC. The underlying production planning and control issues of the company were found to be consistent with the literature associated with the limitations of MRP and a good fit for the core issues traditionally addressed through TOC applications such as Drum Buffer Rope (DBR). The integration of this aggregated buffer management approach with MRP dependent demand within DDMRP provided further enhancements applicable to the company. This evaluation involved simulation, which shows the merits of DDMRP in the area of standardization of production-relevant decision-making and stock adjustment towards improving availability shown by roughly 45% reduction of high and low inventory alerts and a 95% reduction of stock outs over the period in focus. However, it is acknowledged that the improved simulated performance was not fully attributable to the adoption of DDMRP concepts.

Research limitations/implications – The document uses a selection of relevant pieces of the literature from the areas of MRP/ERP, continuous improvement and DDMRP that have the potential to be supportive for assessing DDMRP as a performance improving methodology. However, since the amount of literature available on DDMRP is very limited, a comparison of

the results with others' findings is not possible. Furthermore, the primary data used originates from one specific company only. The resulting case study approach is therefore limited to a single case, which might limit the generalizability of the findings to an extent. However, since many companies are suffering from MRP shortcomings and TOC ideas like buffer management or dynamic buffers have been proven to deliver promising results in many applications, at least an assumption of a certain degree of generalizability could be justified. Further research needs to verify if the findings are replicable in comparable scenarios.

Originality/value – DDMRP is a new commercial development that has not previously been the subject of a research study. The value of this research is in evaluating the key features of this planning and control system using real company data. By doing this, it is one of the first published projects in this area.

1 Introduction

The theory underpinning best practice in the planning and control of manufacturing companies has developed significantly in recent decades but there is has been limited evidence of this being integrated within the generic information systems now commonly referred to as enterprise requirements planning (ERP) systems. Materials requirements planning (MRP) was and still is a central feature of such information systems. Originating in the 1960s MRP (Orlicky,1975) has been added to over the years (Plossl, 1995), but the underlying module has not significantly changed to reflect the new emphasis on the importance of managing and reducing variability. However, there is evidence that this may be about to change with the third revision of Orlicky's MRP book (Ptak and Smith, 2011). This latest book embraces the concept of demand driven (DD) MRP which is the focus of this research. This research aims to evaluate this latest MRP development through a case company that has been a long established user of ERP exhibiting many of the issues DDMPR claims to address.

1.1 Case company background

This research project takes place at a printing ink manufacturing company called InkCo for confidentiality reasons. InkCo is located in Southern Germany and produces many market-leading inks in the application areas of screen, pad and digital printing. However, InkCo is suffering from unacceptable levels of due date performance resulting in expediting activities being visible almost every day all around the factory and warehouse. The results of some preliminary research are presented next to better describe the background of this study.

InkCo uses an enterprise resource planning (ERP) system, which incorporates a standard MRP system for production planning and control. However, this well established system exhibits some limitations apparently encouraged by this planning and control system.

InkCo uses the annual sales budget as the basis for determining concrete demand figures to arrive at the master production schedule (MPS). Resulting demand figures as well as suggested minimum and maximum stock level settings seem to be only loosely connected to reality. This is true because the basis is formed by forecasts that might turn out to be wrong for obvious reasons. Furthermore, MRP is only used to generate proposals for finished goods rather than creating them also for intermediate products all the way down the bill of material (BOM). The resulting manual work beside all efforts delivers often only sub-optimal results.

Additionally, the performance of the production function is measured by focussing on output figures of finished goods. This encourages planners to minimize “unproductive” times caused by setup and cleaning. The result is batch sizes often too high in relation to actual demand and production lines being occupied too long by work orders delivering stocks not really needed in favour of producing actually required products. The initially mentioned expediting activities include conflicting work order priorities and quantities that are changed on a permanent basis to satisfy the demand of more urgent productions.

The previously identified planning problems led to inventory items with too much stock on one hand and to those with lower stock levels than needed on the other. The resulting instability of the whole system leads to expediting and oscillating priorities. This claim becomes more support from common behaviour of the sales function. Their performance is measured on order intake, which causes them to ignore current production load or on-hand stock while accepting customer required delivery dates. Further effects include availability issues for standard raw and packaging materials. The permanent changes together with inadequate usage of the existing MRP seem to be the main causes for this issue. Altogether, these issues further accelerate the expediting activities and oscillating priorities between urgent orders and stock replenishment needs.

It becomes obvious that InkCo is suffering from some major issues at the heart of production planning and control, which makes it a valuable activity to explore this area further to arrive at an adequate understanding and to come up with improvement proposals. Since InkCo is not operating in isolation from developments in the theory of production planning and control, it seems to be worthwhile to consider relevant pieces of related theory next.

The development of DDMRP

The goal of most companies is to make money (Goldratt and Cox, 1984; Klein and Debruine, 1995) and although this concept has not changed over the last decades, the environment has. The introduction of globalisation has caused the death of the old “push and promote” style manufacturing and increased levels of volatility and variability of demand have imposed pressures on companies and their policies and procedures.

Most manufacturing companies are using ERP systems today for many if not most departments and functions. Whilst the environment has changed dramatically since the mid-

1970s, the core component used for production planning and control has not. This MRP module has been first documented by Orlicky (1975) as only a few hundred companies were using it. Since then it has become the standard way of managing the manufacturing function. However, more and more inadequacies or misfits with a changed environment let to the development of MRP II documented in Plossl (1995). Since the developments have only achieved enhancements to the functionality (e.g. consideration of capacity), the MRP core stayed the same. This is confirmed by Ptak and Smith (2008) in their ground-breaking article that introduced the idea of actively synchronised replenishment (ASR), the later demand driven MRP (DDMRP) (Ptak and Smith, 2011). They have developed a concept that embraces the strength and validity of MRP while taking care of its weaknesses in today’s environment. New components and procedures are based on various well-known methodologies including the Theory of Constraints (TOC) and lean manufacturing.

In the 1980s Eliyahu Goldratt developed TOC as a systematic approach to identify the bottlenecks in companies preventing them from achieving their goal of making money. It originally consisted of a set of tools to conduct a comprehensive analysis of business systems to determine the often few limiting constraints (Goldratt, 1990). Moreover, the approach explicitly includes the idea of continuous improvement into its toolbox being called the five focussing steps. Beside many successful applications to mainly manufacturing organisations as a production scheduling technique in its early years (Mabin and Balderstone, 2003), its continuous development has provided the three paradigms of performance measurement, logistics and problem solving. It therefore represents not only a set of tools or techniques, but also a fully-fledged management philosophy of its own right (Klein and Debruine, 1995).

Since developments in the theory relevant to production planning and control made during the last few decades seem to be addressing some if not all issues InkCo is suffering from, their evaluation in terms of their helpfulness to improve current results could be justified. Especially the evolution of the central MRP module in the form of DDMRP that embraces current knowledge about MRP and continuous improvement ideas resulting from TOC or lean approaches makes it a valid object for further research.

1.2 Research problem

Researchers have reported many successful applications of TOC in manufacturing, but later parts of this document shall identify that incorporation of its ideas into packaged software products is still a rare phenomenon. However, Goldratt has stressed many times the importance of using software in conjunction with the TOC concepts rather than only the concepts alone (Goldratt et al., 2000).

The introduction of DDMRP came from a different direction. Thus, Ptak and Smith (2011) justified their concepts on a thorough review and critique of standard MRP packages. Whilst they cannot withhold the close relationship between DDMRP and its main predecessor TOC, what later chapters will uncover, their ideas are mainly manufacturing and IT driven. However, DDMRP's predecessors or roots are widespread and do not only include ideas from TOC but also from prominent methodologies as lean manufacturing, six sigma and many more (Polge, 2013).

This research is an attempt to use the interrelated concepts of TOC and DDMRP to determine their appropriateness in a specific manufacturing environment. The analysis and evaluation will include the TOC thinking processes tools in testing the assumptions and fit with the generic TOC approach. Based on this understanding about the issues present at the case company, DDMRP is the subject of research that should provide indicators of its applicability, usefulness and appropriateness to the given environment.

The research takes place in a printing ink manufacturing company, for which the synonym InkCo is used throughout the document for confidentiality reasons. The author works for InkCo as its Chief Information Officer, which causes that the research task and the related outcomes are expected to be usable at the workplace.

1.3 Research gaps and contributions

The concept of DDMRP to be examined in this research project is quite new, since it was first explained to a wider public in Ptak and Smith (2008). It then gained more attention during many conferences until a very comprehensive book was published (Ptak and Smith, 2011). It is the third revision of a series of standard documentations about MRP started by Orlicky (1975) and continued by Plossl (1995), which opened access to an even wider audience to DDMRP. Since 2008, some organisations have been founded or included DDMRP into their portfolios in order to further develop the standards, to provide training and certification and also to make money by offering consultancy services (e.g. Demand Driven Institute, Constraints Management Group or Demand Driven Technologies).

However, the amount of literature available on DDMRP is still limited to a few articles (e.g. Ptak and Smith, 2008; Ptak and Smith, 2011a) and to less than a handful of books (e.g. Ptak and Smith, 2011; Smith and Smith; 2014). The available literature and some websites report successful implementations of DDMRP, but only supported by some key performance indicators or improved business results. The author sees the reason for this negligence not in the unattractiveness of the concept but more in the fact that consultants want to make money and are not willing to publish their toolkits. The resulting lack of comprehensive research on DDMRP is seen as a gap that this document tries to narrow.

1.4 Aim and research questions

The aim of this research is the identification of an appropriate set of policies and procedures that establishes an effective and efficient production planning and control function at InkCo's operations. The aim is addressed by breaking it down into more manageable and even inter-linked research questions (Moon, 2007). First, the focus lies on ascertaining the nature of demand and the current production planning and control strategy. This helps to understand the relationship between demand features and current planning performance as the basis for the development of improvements. The answer to the related first research question should provide undesirable effects or performance issues of the current ways of working. The second research question to be answered is intended to develop and justify a new set of procedures that form a coherent model of production planning and control. The main focus is set to an evaluation of the DDMRP methodology that embraces standard MRP and ideas from continuous improvement methodologies. After having developed answers to the two main questions mentioned, the aim of the document is addressed. However, some thoughts about the generalizability of the findings should be made to prepare findings to be verified and used in other circumstances.

Identification of an appropriate system for production planning and control for InkCo

The broad nature of the aim should allow for stating research questions that allow for a detailed investigation and solution development to be undertaken while addressing it. This perfectly fulfils the exploratory and explanatory research purposes identified by Saunders et al. (2007).

1. *What are the issues in InkCo's current planning and control system that limit performance?*

A full understanding of current ways of working is an almost mandatory prerequisite for starting an improvement initiative (Deming, 1986). However, he further states that simple knowledge about processes is not likely to be helpful if people do the wrong things. In this light, this question explores the current ways of working together with reasons for having them established as observable today. However, this development of knowledge is only one part of the answer since later improvement can only be verified against current performance levels. Therefore, an assessment of the appropriateness and performance of the established ways of working is intended to enhance the answer. This is expected to lead to a set of undesirable effects of the current ways of working that provide direction for later improvement.

2. *To what extent do the features of MRP/ TOC/ DDMRP address these limitations?*

"The effectiveness of any system has to be judged by the result it achieves." (Ptak and Smith, 2008) Therefore, using the insights gained about issues in InkCo's production configuration to develop a solution being capable of showing improved results makes perfectly sense. Advice from the available literature will be used in conjunction with findings made about InkCo to justify the suggested solution. Moreover, an examination of the appropriateness of the new methods is intended to provide evidence for validity and usefulness.

Based on the aim of the document broken down into two research questions, their nature and breadth seems to be adequately chosen. Furthermore, they almost naturally separate the subject into logically split tasks.

1.5 Outline of the document

In this section, the following main chapters of this document are briefly summarised to provide an idea about the structure and the line of argument used. The first introductory chapter has already described the background of the study while putting the most relevant theories in relation. Furthermore, the identification of the research problem has led to the aim of the research project being broken down into a logical chain of two research questions. Some thoughts about the likely contribution of this research to the overall body of knowledge have concluded the main part of this chapter.

Update on the literature

The chapter is divided into three parts in order to provide knowledge about the three main areas of theory useful to this research separately. However, the last part tries to establish connections between the previous two and the concept of DDMRP.

First, the history of MRP is described from its very beginnings in the middle of the last century until its today common application and integration in ERP systems. Since implementation of the most recent incarnation in ERP systems is quite often subject of discussion about problems with achieving budget and completion targets, common critical success factors are identified. A two-folded discussion about organisations and economic impact of ERP systems provided the ground for the following evaluation. Here, major weaknesses and strength are shown that put the findings in context of the economic situation as of today. The results are expected to act as linkages for the third part of this chapter.

Second, the Theory of Constraints (TOC) is introduced by describing its quite short history from its introduction in the eighties of the last century until the latest developments. The three main paradigms of logistics, global performance measurement and thinking processes are identified and described in order to provide a fuller understanding and to introduce ideas and concepts that are intended to be used in later parts of this document. Since this research is grounded in the world of manufacturing, special focus is set on TOC in manufacturing and its concepts for Make-to-Order (MTO) and Make-to-Stock (MTS) or better Make-to-Availability (MTA). A concluding evaluation shows TOC applications and summarises its effectiveness and value to organisations based on the literature.

Finally, the concept of DDMRP is described as it is of central importance to this research project. In an introductory part, the main issues of current MRP applications are contrasted with ideas and concept resulting from TOC. This is intended to prepare the ground for the following description of DDMRP and to show its origins. After that, the five main components of DDMRP being strategic inventory positioning, buffer profiles, dynamic buffers, demand-driven planning and highly visible and collaborative execution are presented. The subchapter is concluded by an evaluation that identifies freshness of the model and the resulting scarcity of literature. However, while relating its components to its TOC origins and to the identified MRP flaws, it could be judged as being quite promising and surely worth further testing.

Research methods

This chapter provides the research plan and its justification in order to guide the whole project. The first step uses the research questions stated previously and breaks them down into more manageable sub questions that also act as an aide-mémoire for later case analysis. Following this, the research methodology is defined and justified together with a description of qualitative and quantitative methods to be used. Special focus is set on the single case study design that is applied to this study to show possible limitations and to justify its selection. The following section on instrumentation identifies the sources of data and the related collection procedures. In a second part, an attempt to assess the validity and reliability of the research is made to justify the selections shown. To round up this topic, some final thoughts about any research bias are provided.

The research project uses personal observation, semi-structured interviews and internal surveys as its main methods for collecting the data from people and to develop an understanding of the processes and procedures involved in the current system. Unrestricted access to the database of the current ERP system is helpful for verifying the findings and to retrieve the data required for later simulation activities. The latter is reflected by laying out the data analysis procedures. Here, the development of the new model is described as being mainly based on findings from the literature. It is the intention to provide evidence for the fit of the current situation at InkCo with generic assumptions and cause and effect relationships resulting from the theory. After this first stage of research, the second stage moves the focus away from theory towards more practice considerations. The intended simulation of the new model by using real data from the current system is described. Finally, the research procedure is briefly summarised to ensure that all information given in this chapter is connected into a coherent tree of activities.

Analysis

This chapter is intended to provide the results of the research activities. First, the case company is described, which leads to a quite intense discussion of its supply chain configuration and the way annual budgeting and demand recognition are implemented. This part is designed to end up with a list of undesirable effects of the current system that are intended to act as starting points for the development and later justification of an improved system for production planning and control. A consecutive identification of the core conflict and an attempt to break it leads to the identification of a new system more suitable in terms of its performance potential.

Simulation

This chapter provides a discussion of selected products that have taken part in a simulation of DDMRP methods. The results show positive and negative stock adjustments according to individual product demand and its variability. Furthermore, its potential of improving product availability is tested. The overall aim of this simulation is to establish an information base that is essentially important for deciding if DDMRP might be the future way of performing production planning and control at the case company. Results of the simulation shown in the final part of the chapter satisfy this need adequately.

Discussion

After having presented the case analysis and the simulation results, the answers to the research questions need to be developed in order to address the aim of this research project. The first part of this chapter joins all findings from the previous two chapters into a coherent picture of the actual situation at InkCo. Sharing this ground, ideas about what to be changed to achieve significant improvements are presented. Both parts are contrasted with the literature to show support and fit of the ideas with those others have already suggested in similar settings. Based on these general findings, the answers to the research questions are developed and justified. Some thoughts about the generalizability of the findings made provide an idea of how they could be incorporated into future studies on the subject.

Finally, some conclusions are presented that summarise the findings made as well as identifying limitations of this research that could lead to further research opportunities.

2 Update on the literature

2.1 Introduction

The main purpose of this chapter is characterised by two equally important motivations. First, the main concepts being useful for achieving the aim of this study are presented. This includes recent knowledge about ERP systems in organisational settings. An overview leads to more implementation-focussed material, which concludes with aspects that concentrate on the impact of introducing and operating such systems to the organisation and on its financial performance. This first part is followed by a section introducing the main principles of the TOC methodology by explaining the basic concepts and its embedded toolbox being the thinking processes. As this research is about implementing change, the next part is devoted to its prominent component of on-going change. Finally, some recent knowledge about the application of TOC to organisations should prove its genius by providing facts that show its benefit.

While this first section was mainly aimed to prepare the ground, the actual model development happens now. Since the existence of ERP systems in manufacturing organisations is almost a given today, solutions for compensating their identified weaknesses seem to be rare. Therefore, an attempt to use concepts from the TOC methodology to improve the results of ERP systems is undertaken to develop a model from the literature. Such pieces of evidence are used to justify the model as being promising enough for later simulation and testing. An evaluation of likely strength and weaknesses acts as a further preparation. Conclusions are intended to summarise the findings made.

2.2 Enterprise resource planning

Since the 1990s, ERP systems have become more and more common for manufacturing organisations. They have been almost permanently evolved and enhanced from their predecessors of the early 1970s (MRP) over more enhanced versions (MRP II) (Elragal and Haddara, 2012). Even today, when a focus is set on the definition and development of ERPII, the impression of permanent change is perceptible (McGaughey and Gunasekaran, 2007). The main difference between the defined stages of evolution is the focus of the software. While early MRP implementations concentrated mainly on inventory and production planning (Orlicky, 1975), MRP II packages widened the focus by including other business processes and perspectives along the supply chain as procurement, order processing, distribution and the concept of capacity (Jacobs and Weston, 2007). One further enhancement included in MRP II was the integration of formerly external entities as other plants, warehouses and distribution centres (Becker and Rosemann, 1997; Klaus et al., 2000). ERP systems continued this trend of broadening the focus by incorporating the whole organisation. The focus is set on key business functions not only on those being related to operations or manufacturing (Davenport, 1998). The software is also seen as a means for integration of departments, functions and information (Kumar and Van Hillsgersberg, 2000).

Based on the brief history presented it should be possible to find a meaningful definition for ERP systems. However, a discussion shown in Klaus et al. (2000) highlights some obstacles concluding that it is difficult to arrive at a common definition as the meaning of ERP is “in the eye of the beholder”, “being a function of perspective and intent”. Despite the fact that such difficulties and resulting misunderstanding are acknowledged, a working definition for the rest of this document is needed. Blackstone and Cox (2005) came up with the definition that ERP systems represent a “framework for organizing, defining and standardizing the business processes necessary to effectively plan and control an organisation so the organisation can use its internal knowledge to seek external advantage”. This definition is suitable due to its focus on “the broad scope of applications that fit under the ERP framework” (Jacobs and Weston, 2007). The following Figure 1 summarises recent understanding of the design and content of ERP systems influenced by work shown in Chen (2001), Rashid et al. (2002) and Shehab et al. (2004).

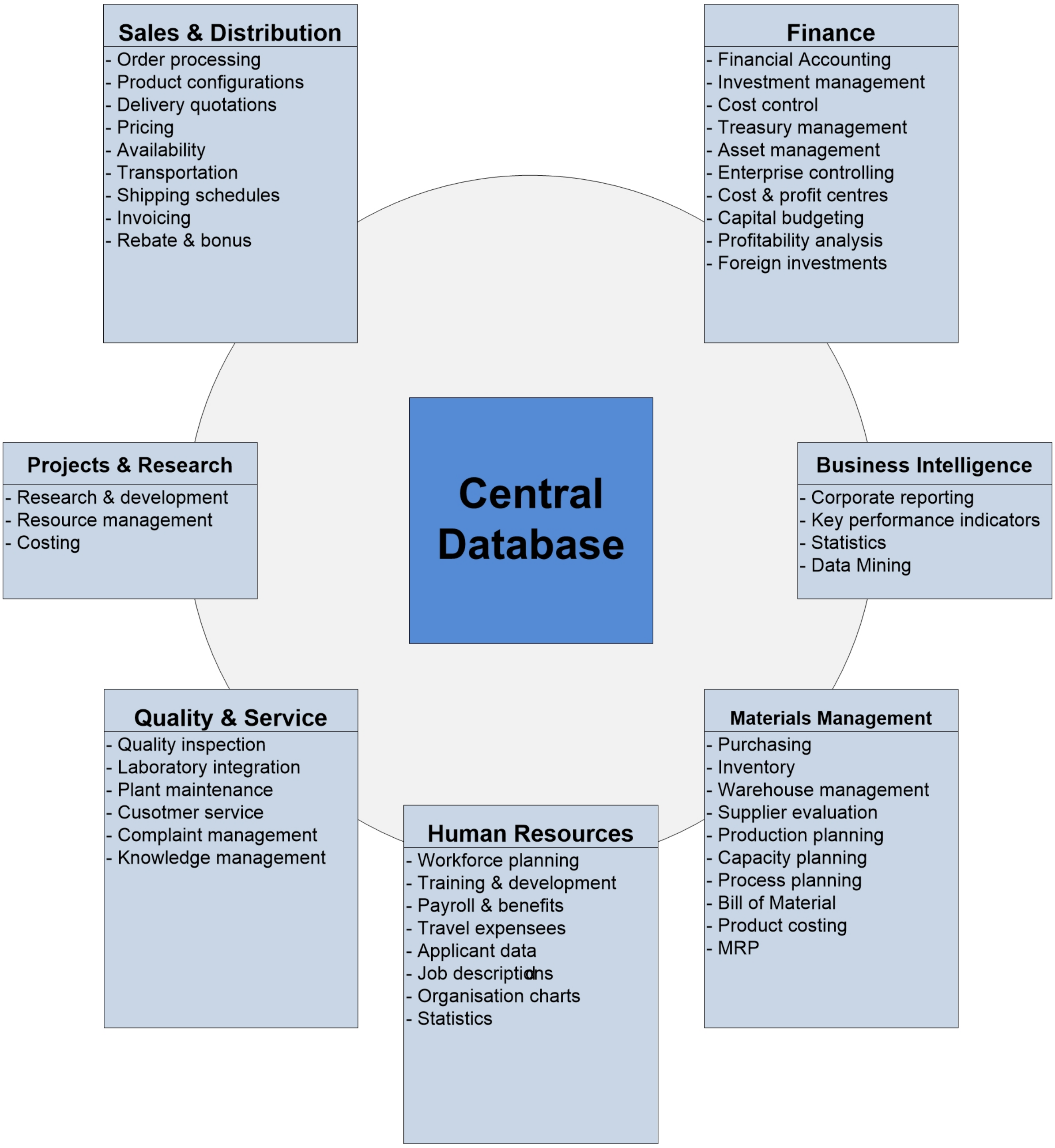

Figure 1 – ERP system modules

Since the focus of this document is manufacturing planning and control, the following parts concentrate on ERP parts related to this purpose. However, they have connections to all other parts as finance (cost and control), business intelligence (statistics and control), human resources (job profiles and training), quality and service (quality management and control), projects and research (proof of concept and resources) and sales and distribution (availability and delivery quotations). Although the given connections do not claim to be an exhaustive collection, it shows the interconnectedness of ERP systems reflecting the whole organisation (Gupta, 2000; Siriginidi, 2000).

2.2.1 Production planning and control

It is a common tendency observable in private and professional life that continuous advancement of computer processing power and software application have changed almost everything that was standard one or two decades ago. Examples for this are the evolution of mobile phones, the transformation of written communication towards email or the development of social networks. In all of these examples, former standards or procedures were advanced and developed to a state where any traces of the early predecessors are not even recognisable anymore. In the case of production planning the situation is different. Ptak and Smith (2011) clearly identified that MRP concepts and procedures developed in the early 1970s are still at the heart of even the most recent ERP packages' manufacturing planning functionalities. For this reason, one needs to understand the MRP origin and evolution until today to be able to evaluate its appropriateness in later parts of this chapter. Each era is discussed briefly in turn.

Pre-MRP era

In the first half of the 20th century, a quite thorough understanding of the manufacturing process was developed by various researchers including Harris' (1913) EOQ model, Gantt's (1919) chart for graphically displaying and planning manufacturing orders over time including required resources and Wilson's (1934) reorder point system and the introduction of the safety stock principle. In the later 1940s Wilson combined his ideas with the EOQ, but was not able to reach high levels of application due to the lacking computer availability and power (O'Gorman, 2004).

The increasing availability of computers in the 1960s allowed for application of the concepts described in industrial settings. The main focus was set on optimising the results in given settings (Olhager, 2013). Early applications were mainly focussed on inventory control systems (Orlicky, 1975), but also included production planning and scheduling (Conway, Maxwell and Miller, 1967). This all led to the development of a system called MRP in the late 1960s (Jacobs and Weston, 2007) that will be described next.

MRP

Starting in the early 1970s, material requirements planning (MRP) became widely adopted by manufacturing organisations seen as "the new way of life in production and inventory management" (Orlicky, 1975). His book together with an article by Miller and Sprague

(1975) became the first descriptions of the then already very popular system for determining demand. However, due to the still quite expensive computer technology, popularity needs to be seen as approximately 700 applications in the mid-1970s (Orlicky, 1975). One of the main influences of MRP was on the planning process of manufacturing companies, because of the fact that only finished products needed to be planned based on forecasting or historical data. MRP considered the bill of material (BOM) to identify demand for intermediate products as well as for raw material based on the calculated demand for finished products. This concept of dependent demand (Wight, 1970) was seen as the most influential component of early MRP systems, because it relieved manufacturing organisations from the requirement to plan and control inventory at all levels of the BOM.

MRP required a master production schedule (MPS), realistic lead-times, correct inventory levels and a valid BOM to calculate material, component and assembly requirements (McGaughey and Gunasekaran, 2007). They continue to identify that computing power was still a limiting resource that allowed only for periodical (often weekly) calculation runs. Therefore, lead-times worked backwards from a due-date to an adequate order or production start date. This allowed for using MRP systems not only for calculating demand but also for scheduling manufacturing orders on the shop floor (Shehab et al., 2004; Olhager, 2013). Following higher rates of adoption, MRP systems and the underlying data got augmented and enriched to allow for further functionality including capacity requirements planning, manpower calculations, distribution management (Robinson, 2006; McGaughey and Gunasekaran, 2007). Finally, during the later part of the 1970s one major obstacle of only periodical calculation runs could be removed from MRP systems by the introduction of cheaper computing power (Jacobs and Weston, 2007; McGaughey and Gunasekaran, 2007). The resulting transformation of MRP systems from being regenerative towards offering almost real time data allowed for even better reflecting the reality of the production floor (Ptak and Schragenheim, 2004). Furthermore, increased computing power allowed for integrating even more functions into the system. This transformation towards a real-time planning and control system spanning wider areas and functions of the manufacturing organisation is seen by McGaughey and Gunasekaran (2007) as the trigger for developing MRP II methodology, which is described next.

MRP II

Following the trend of including more and more functionality into the former MRP systems, the term MRP II was born meaning manufacturing resource planning. The change of meaning of the acronym MRP was intended to reflect the evolvement of the system from being solely focussed on the availability of material in any form towards representing a sophisticated planning and control system for resources in the manufacturing organisation (McGaughey and Gunasekaran, 2007). According to Jacobs and Weston (2007), a shift in manufacturing industries away from optimizing existing configuration for availability and efficiency towards more marketing and sales focussed approaches that put quality into focus demands for higher levels of process control and a focus on reducing overhead cost. That is the point when cost controlling features, general ledger functionality, personnel and database technology became common parts of systems being installed (Shehab, 2004). A common goal was to be able to plan and control almost all resources of a company in order to improve the efficiency of the manufacturing organisation (Chung and Snyder, 2000; Mabert et al., 2001). However, the heart of planning and control was still represented by the common MRP logic of the 1970s (Ptak and Smith, 2011; Olhager, 2013).

Beside the tendency to include most resources and parts of the organisation into the MRP II system, some new functionality became standard for such systems. The master production schedule (MPS) determination that was formerly determined as an activity external to MRP became part of the systems' capabilities (Plossl, 1995). According to Klaus et al. (2000), the MRP II takes the sales forecast as its main input to determine the master production schedule that represents the gross primary demand. The materials management function calculates the demands for secondary products by considering demand and consumption based information. These material demands are then consider into a capacity management stage that tries to match demand with machineries. The resulting raw production schedule is taken into comparison with available resources to arrive at a viable schedule that results in production orders being released to the shop floor.

As an additional feature of the master production schedule the so-called available-to-promise (ATP) functionality was introduced (Olhager, 2013). Framinan and Leisten (2012) describe the primary value of this functionally by being able to check how much of a specific material is available for immediate delivery or at a certain point in time.

Given this enormous success resulting from improvements in accuracy of planning and the availability of integrated procedures, Landvater and Gray (1989) already identified that the sheer amount of functions being integrated into a MRP II system did not relate directly to its value to the organisation. Their difficulties with drawing a line between what is part of a MRP II system and is not led to the development to the almost all comprising ERP systems of the 1990s that are discussed next.

ERP

At the very beginning of the 1990s, Wylie (1990) coined the term enterprise resource planning (ERP) originally invented by the Gardner Group. These systems evolved from their MRP II predecessors by providing functionality for the whole value chain (Shehab et al., 2004; Siriginidi, 2000). Not only the integration of a full range of back-office functions as order processing, distribution, warehouse, finance, human resources and quality to name a few became common, but also functionality that focuses on planning and control of external resources as supplier schedules or dynamic customer demand (Chen, 2001).

Another feature that became more and more common for the then-called ERP systems was a focus on advanced planning (Olhager, 2013). He explicitly stresses the importance of the introduction of sales and operations planning functionality (S&OP) in this new generation of enterprise software. He characterises the concept "as the long-term planning of production and sales relative to the forecasted demand and the complementary resource capacity planning". Ling and Goddard (1988) identified the main benefit from introducing a long-term perspective (15-18 months) into organisational planning by being able to evaluate investment decisions involving long-term acquisition processes against plans of sales, operations and inventories. Olhager (2013) integrates S&OP into the four-tier planning and control structure from long to short range: S&OP, MPS, MRP and shop floor control. Olhager and Rudberg (2002) introduced two planning strategies at the S&OP level, being chase and level. While the first is ideal for high-volume standardised products with short lead-times, the latter is good for low-volume products that come in many variations and are affected by long lead-times. This deviation from the former "one-fits-all" approach to planning was better able to deliver improved operational results (Olhager and Selldin, 2007; Thomé et al., 2012).

Finally, the approaching year 2000 (Y2K) and the anticipated problems with tailor-made software packages triggered an even accelerated growth of ERP systems, which were getting even more sophisticated and full of functionality (McGaughey and Gunasekaran, 2007). The ability of such systems to serve not only the needs of manufacturing organisations but also by many other industries and the fear for Y2K effects caused a broad spread of ERP systems that were also getting more and more affordable for medium and smaller organisations (McGaughey and Gunasekaran, 2007; Elragal and Haddara, 2012).

Recent developments

In line with many authors as Jacobs and Weston (2007) or Olhager (2013) and personal experience of the author with manufacturing and non-manufacturing organisations, ERP systems are a common feature today. The trend of adding more span and functionalities of the 1990s continues until today (McGaughey and Gunasekaran, 2007) by making customer-focussed applications as CRM systems standard components on the external side and more internally focussed technology as BI modules on the internal side.

Furthermore, according to Olhager (2013) current market conditions in a globalised world characterised by shorter lead-times and higher levels of competition and increasing levels of variation demand for better supply chain support in current ERP systems. However, authors as Chopra and Meindl (2001) or Ptak and Smith (2008) concluded that quite often additional software outside the ERP system is needed for this task, because current ERP systems do not yet offer adequate functionalities. Two main features required for external planning and control are collaborative planning and forecasting (CPFR) (Lapide, 2010) and vendor-managed inventory (VMI) (Marques et al., 2010). Olhager (2013) concludes with the claim that it is still more difficult than expected to establish proper supplier and customer integration with today’s systems and that it might need another decade to arrive at a similar level of obviousness as for internal planning and control.

However, can one expect that the race for internal optimisation of the supply chain is already over? The literature on supply chains in relation to continuous improvement has provided very popular concepts like Six Sigma, Lean manufacturing or the Theory of Constraints that show significant adoption rates in various industries. Current ERP systems according to Ptak and Smith (2008) show little functionality for comprising such ideas. It is fact that internal planning and control of most if not all ERP systems is still based on the MRP logic of the 1970s. Resulting limitations are shown in subsequent sections, but one needs to ask the question if it is likely that ERP systems will adopt each and every new business improvement fad. If not, there has to be a different approach of incorporating continuous improvement ideas into current ERP systems. A later part of this chapter tries to develop an example for such an approach on the basis of findings from the literature.

The following Figure 2 summarises the evolution of enterprise software by using information from Olhager (2013) and Rashid et al. (2002).

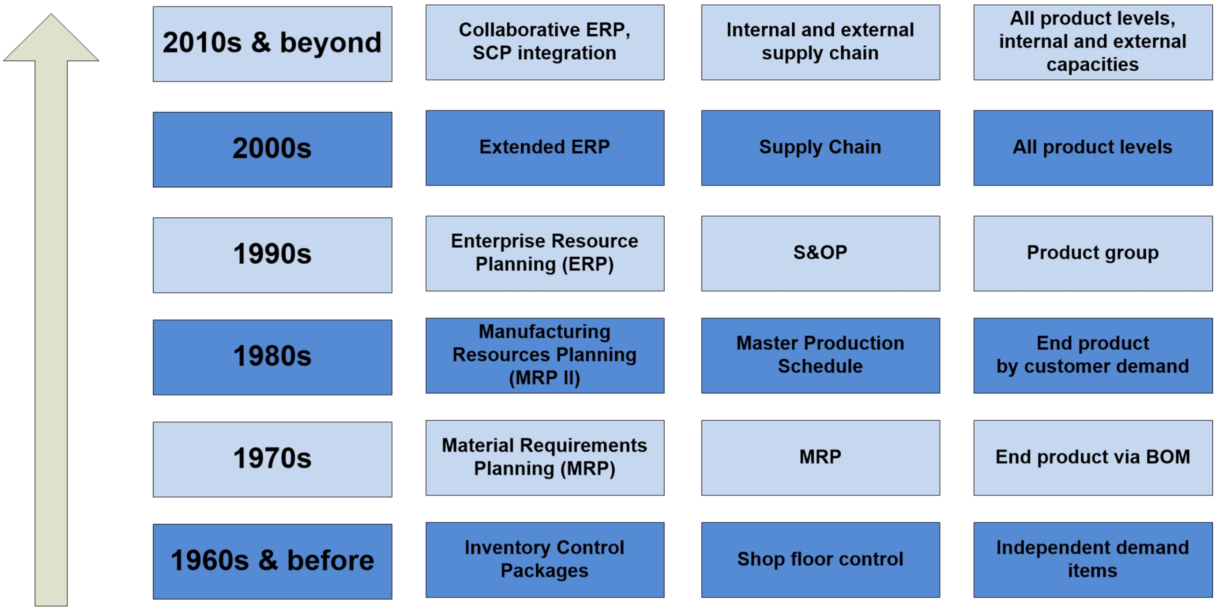

Figure 2 – Enterprise software evolution

2.2.2 Critical success factors

Most businesses are facing increasing competition, expanding markets and increasing customer expectations in our globalised world (Shukla et al., 2009). Their answers to these challenges include lowering the total cost in the supply chain, shorten throughput times, reduce inventory levels, increase product choice, improve delivery date performance, provide expected quality and effectively coordinate global demand, supply and production (Shankarnarayanan, 2000). Some of these tasks involve increasing levels of collaboration between manufacturing companies, their suppliers and customers (Fawcett et al., 2008). Therefore, companies have to upgrade their information systems as competitors are also doing this (Umble et al., 2001). They identified the introduction or improvement of ERP systems as the common way to achieve the goals for maintaining competitiveness. Umble et al. (2001) identify two major benefits of ERP systems being “a unified view of the enterprise that includes all departments and functions” and “an enterprise database where all business transactions are entered, processed, monitored and reported”. However, the majority of ERP implementations fail (Langenwalter, 2000; Ptak and Schragenheim, 2004) due to many reasons including strategic goals not well defined, no adequate commitment of top management, lacking project management during implementation, missing commitment of the organisation to change and staffing issues in the implementation team (Umble et al., 2001). Thus, it is important to identify factors that help to achieve a successful result. Among many pieces of research on this topic, Umble et al. (2001), Finney and Corbett (2007) and Grabski et al. (2011) were used to identify a set of core factors that are briefly discussed in turn.

Business process reengineering

ERP implementations are often used to establish changed business processes (Nah et al., 2001). Best practice processes of ERP vendors often need to be implemented or the project is seen as a chance for introducing long-term planned changes (Wenrich and Ahmad, 2009). It is crucially important to understand current practices prior to investigate possible changes in order to improve business capabilities. As ERP systems embed and reinforce the execution of defined processes, understanding the impact of changes is required (Butler and Gray, 2006).

Commitment by top management

An ERP implementation involves extraordinary effort of team members to fulfil their project commitments while often being still in charge in their old job. Furthermore, significant resources in form investment and management are required for a successful outcome. Umble et al. (2001) clearly identify that without support from top-level management projects are likely to fail. Reasons for this might come from lacking management of conflicts, failure to make decisions relevant to the project on time or from inadequate provision of monetary resources. In general, the creation of a climate characterised by clear goals and priorities should be facilitated by leaders of the organisation.

Project team and management

Umble et al. (2001) are very clear about the importance of staffing and management of the implementation team. Decisions about full or part-time dedication of team members need to be carefully made. An adequate mix of capabilities in often multi-disciplinary teams is also important to ensure proper levels of knowledge. Furthermore, since external consultants are most often part of the implementation team, management of goals and priorities across departmental or organisational boundaries is sought.

Organisational change management

Aloini et al. (2007) have identified inadequate change management in ERP projects as one of the major reasons for project failure. Such projects have unique factors in comparison to other forms of change being process reengineering, introduction of new systems and the integration of external consultants. This requires adequate training as well as explanation of the underlying reasons (Somers and Nelson, 2001). As a certain level of resistance should always be expected (Taylor, 1998), Bridges and Bridges (2000) suggest a managed transition period characterised by the three distinct processes of saying good-bye, shifting into neutral and finally moving forward. Beside proper explanation and management, continuous user training has been proven to be helpful (Park et al., 2007).

Training

The implementation of an ERP system requires users to learn how to perform their tasks within the framework of the system. If users have not developed adequate levels of knowledge then low levels of acceptance (Grabski et al., 2011) and the creation of workarounds that manipulate the systems' procedure might be the result (Hutchins, 1998; Laughlin, 1999). Research suggests that training should start well before the implementation starts to create awareness and acceptance (Umble et al., 2001). During the implementation phase, training should be continued as a permanent activity rather than as a one-time initiative to gain trust and problem–solving skills with the means of the new system (Yu, 2005; Sein and Santhanam, 1999). Once the new system is operational, users might know the basic techniques to fulfil their job requirements. To be able to gain a further significant increase of productivity, training should continue even post-implementation (Allen, 2008).

User acceptance

According to Grabski et al. (2011) social factors as user acceptance is often neglected in ERP projects although they might have strong influences on the implementation and later usage of ERP systems (Chang et al., 2008). Most ERP implementations are based on "best practices" that are processes suggested by the ERP vendor and modifications that are made during the implementation phase to create fit between the ERP and organisational processes (Mayere et al., 2008). Since users need to learn how to perform their work tasks with the ERP system, adequate training has a significant influence on later acceptance (Grabski et al., 2011). Once business processes are changed during ERP implementation, users need to understand the reasons and their commitment should be sought to gain their acceptance (van der Alst et al., 2007; Al-Mashari, 2003).

The following Figure 3 shows the main factors and establishes influences between them based on findings shown in Grabski et al (2011).

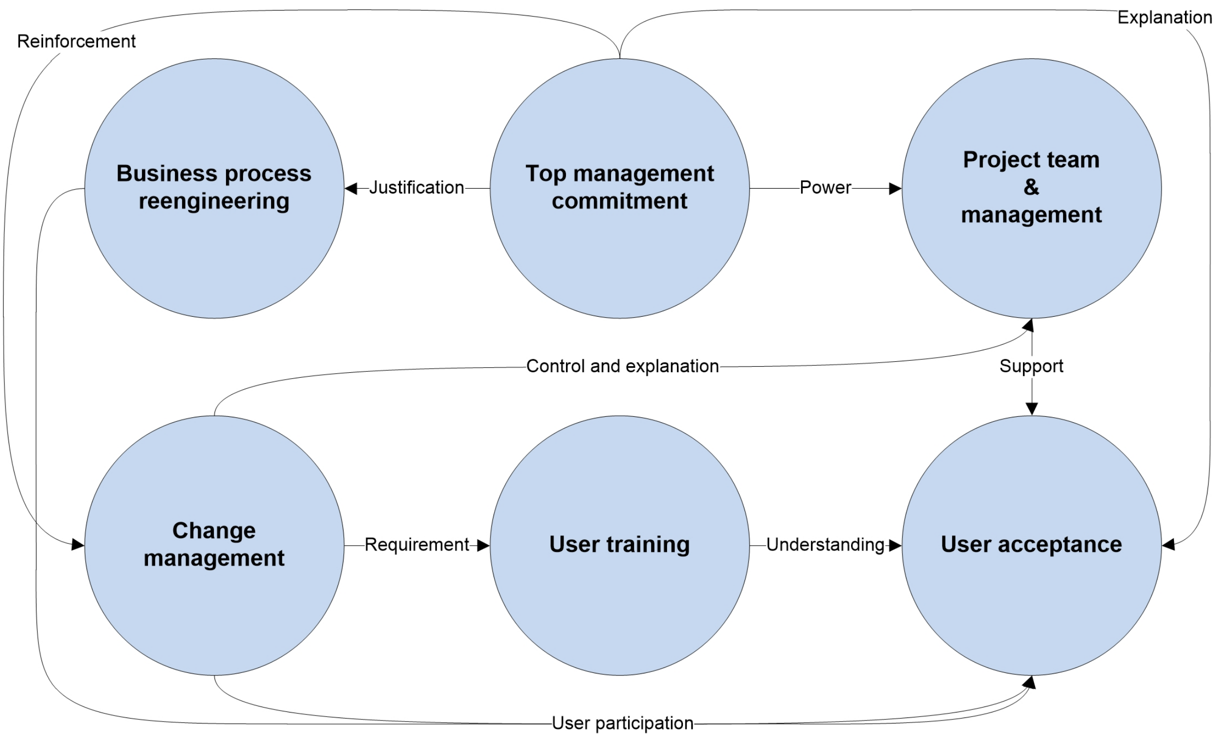

Figure 3 – Critical success factors in ERP projects

2.2.3 Organisational impact

Research by Stewart et al. (2000) has shown that the introduction of an information system (e.g. ERP) could be seen as diffusion of technology in a social system. Therefore, close alignment between the technological and organisational requirements needs to be sought (Raymond and Uwizeyemungo, 2007). Furthermore, Everdingen et al. (2000) suggest that the degree of fit between current processes and the ERP process model is an important system selection criterion. Altogether, careful selection have many positive effects on the implementation phase and on later successful operation by reducing the need to undertake an in-depth process reengineering and limiting the consumption of financial and human resources. The on-going discussion about how an ERP system should be implemented has two main poles. Volkoff (1999) stresses that ERP implementation involves a mutual adaptation between ERP processes and organisation practices. Other authors as Bancroft et al. (1998) support the view that ERP systems embody universally applicable best practice processes that should be implemented without significant modifications. On the other side of the discussion, Swan et al. (1999) find that there is no such thing as best practice processes and that organisations should strive for adaptations of the ERP processes to their unique context to avoid any unnecessary disruptions to their business activities. However, each ERP implementation involves a certain amount of process redesign, new or amended performance metrics and training (Hammer and Stanton, 1999; Markus, 2004). Reengineering of business processes can have different motivations from the simple need due to customer, legal or cost saving goals to the need to adapt to best practices of a specific ERP system (Scheer and Habermann, 2000). Grabski et al. (2011) suggest an iterative process between ERP process shaping and the end user. This is useful since the user needs to acquire system knowledge about the ERP process model as a basis for evaluating the degree of fit with current ways of working (Light and Wagner, 2006). This becomes particularly important since most ERP implementations require a certain amount of individual modifications (Light and Wagner, 2006). If this is true, the modification should be developed as close to the organisational requirements as possible. Summarising the discussion about reengineering, one could state that a new system should not automatically be seen as the main justification for changing valued and embedded ways of working. Careful change management is needed to establish acceptance and support by end users for changes by letting them participate at all stages of definition and implementation.

Another aspect of ERP implementations is their relation to organisational culture. Ke and Wei (2008) advocate for the need to achieve a certain degree of fit. They relate ERP success directly to a successful match between the ERP system and the organisational culture. However, other authors like Senge (1994) identify that organisational cultures can be changed by top management to fulfil new requirements (i.e. match with ERP system characteristics). Altogether, a certain degree of fit achieved by making an optimal selection of an ERP system, by adjusting the organisational culture or by mixtures of both should be sought. Davenport (2000) identifies two elements of a rational ERP implementation being preparing the people and preparing the technology. The first step involves creating adequate project structures, discussing the project needs together with users and gain their support, training them in the new system to allow for participation and later acceptance. Exactly these elements of an organisational culture are found to be influential to ERP success. Markus et al. (2000) state that for successful ERP projects an organisational culture should allow for participation and involvement, should not be resistant to necessary change and should include a top management that provides support and that is consistent about strategic goals.

2.2.4 Economic impact

Earlier parts of this chapter have already stated that ERP systems are a common feature of manufacturing organisations today. Critical success factors highlight the importance of the organisation to adapt to and learn the processes being standard to the ERP system. Furthermore, organisations need to make decision where modifications to these standards are required. This moves the responsibility away from IT staff to the classic business roles and functions (Wieder et al., 2006). In the face of all the effort needed to run a successful implementation, they ask the question: “Are those systems worth the money?”

Since ERP implementation involves a substantial investment of human resources and money, the subject has been covered by a growing number of researchers. According to Hendricks et al. (2007), most of the studies assume that ERP projects have a positive effect on operational performance metrics, which as a result improve financial results. Brynjolfsson and Hitt (2000) found that investment in ERP technology has a significant effect on profitability and performance growth and Barua et al. (1995) identified that such investments have a positive effect on internal performance criteria such as inventory turnover. A similar result is shown in McAfee (1999) who explicitly found positive effects of ERP systems on cycle-time improvements and on-time delivery performance. In a more recent article, McAfee (2002) showed that ERP systems are able to reduce order cycle times and by this improve throughput and delivery speed. Another benefit of ERP systems is reported in Bancroft et al. (1998) who identified that the central storage of all data being processed ensures that all planning and control activity is based on the same information. The achieved consistency delivers reliable sources for decision-making and the identification for improvement needs. Hendricks et al. (2007) provide a separate view on the performance effects of ERP systems and SCM systems implemented together. While they are able to confirm positive performance effects of ERP systems in terms of increased Return on Assets (ROA) and Return on Sales (ROS), they found stronger results for SCM investments. This is in line with findings published in Wieder et al. (2006) and Nah (2004). Here, effects on both metrics are improved by the move away from often out-dated MRP II planning functionality towards real time planning (Cheung and Lee, 2002; Hendricks and Singhal, 2003). The following Table 1 summarises the positive findings from a selection of studies by using information from Wieder et al. (2006).

Poston and Grabski, 2001	Hitt et al., 2002	Hunton et al., 2003	Matolcsy et al., 2005	Hendricks et al., 2007
Increased Income Selling, General and Administrative Expenses Cost of Goods Sold/Revenues Employees/Revenue	Sales per Employee Profit Margins Return on Assets Inventory Turnover Asset Utilisation Accounts Receivable Turnover	Return on Assets Return on Investment Asset Turnover	Net Profit Margin Current Ratio Fixed Asset Turnover Sales Days Outstanding Accounts Payable Days Inventory Turnover Sales Change	Return on Assets Return on Sales

Table 1 – ERP and SCM impact measurement in the literature

Despite these almost overwhelming results of investment in ERP and SCM systems, one needs to be cautious about interpreting the results. Hitt et al. (2002) found that most of the benefits occur only three years after the implementation of one single ERP vendor's system. Poston and Grabski's (2001) results are only based on information publicly announced by firms. Hunton et al. (2003) did not find that performance for ERP adopters is significantly better than for non-adopters. Their finding is that financial performance of adopters has not declined during the test period whilst the performance of non-adopters did. Only Matolcsy et al. (2005) and Hendricks et al. (2007) seem to have found unambiguous evidence for a positive effect of ERP systems on firm performance.

Nevertheless, the evidence in form of huge application rates in almost all sectors together with findings from the literature indicate that ERP systems are intended to maintain competitiveness and to improve performance results.

2.2.5 Evaluation

This chapter has shown the evolution of manufacturing planning and control software from MRP over MRP II until recent ERP approaches. The literature has shown that MRP routines developed in the 1970s have been re-coded in modern programming languages but are still at the heart of the ERP planning and control function. Most ERP vendors claim that the universal approach of MRP fits all companies in all industries as so-called ‘best practices’ (van Groenendaal et al. and van der Hoeven, 2008). The last section has identified that investment in single SCM software packages or combined approaches of ERP and SCM investment have yielded better performance improvement than sole ERP projects. This becomes clearer when considering Ho’s (2005) statement that one has to see standard ERP systems as only a part of SCM technologies. Ptak and Smith (2011) promote the view that “at the heart of every supply chain is manufacturing and at the heart of manufacturing is MRP”. Thus, MRP tells most companies “what they have, what they need to make and buy, and when they need to make and buy it” (Ptak and Smith, 2011), this evaluation is focussed on MRP and its appropriateness for planning purposes in the supply chain of manufacturing organisations.

Ptak and Smith (2011) have identified common problems of manufacturing organisations that use MRP as their main instrument for supply chain planning and management through an empirical study. The three identified issues are unacceptable inventory performance characterised by having “two much of the wrong material and too little of the right material”, unacceptable service-level performance described by low on-time delivery performance and high expedite-related expenses and waste identified by permanent curing of the symptoms of the previous two issues in form of overtime and additional freight costs. Although not all companies were suffering from all three issues, a vast majority showed at least one symptom (Ptak and Smith, 2011).

A discussion of known shortcomings in MRP adapted from Ptak and Smith (2008) and Ptak and Smith (2011) seems to be helpful to understand likely connections between MRP and the described issues.

Forecast and MPS. Among many others, Goldratt (2009) has identified that all forecasts and sales plans have one thing in common, which is that they are all wrong. Ptak and Smith (2011) support this view and state that even huge investments in advanced forecasting systems do not provide forecasts that are significantly better. MRP uses this forecast in form of the MPS to calculate demand and to create work and purchase orders. As a function of market volatility and fluctuating customer demand in the short-term the quality alignment between such forecasted demand and real customer orders is not satisfactory. The consequences are often high inventories of wrong items on one side and expediting, overtime, extra freight costs and even missed shipments on the other.

Full BOM runs. MRP pegs down the full BOM down to the lowest hierarchy level independently for each stock-keeping unit (SKU) in cases when available stock is less than exploded demand. The result is a huge amount of orders and a schedule that can easily change triggered by a small change at an upper level material (Wijngaard, 2007). If capacity is considered infinitely then significant priority conflicts are the result. The reason is that almost obviously capacity is never infinite and therefore, huge amounts of work orders for intermediate materials often in small quantities need to be fit in. On the other hand, if capacity is considered finite then an often instable schedule is the results. This is caused by interruptions triggered by material shortages that affect the BOM hierarchy.

Manufacturing order release. MRP does not check parts availability prior to releasing work orders since only lead-time related criteria is used for making this decision. It is a basic assumption of MRP that all parts are available at the time of work order release (Smith and Ptak, 2013). Experience of reality suggests that this assumption is not often true. The result is unnecessarily high levels of WIP and number of work orders active on the shop floor. This is caused by standard MRP suggesting the start of various work orders without having verified full availability of required materials before. Furthermore, frequent changes of priorities triggered by material availability and due date conflicts are another consequence.

Limited early-warning functionality. MRP creates work orders for items that reach the configured safety stock level. There is no visibility of items that are near this level or that might reach this level in the near future due to high customer demand (Plenert, 1999). Furthermore, Ptak and Smith (2008) identify the lacking ability of MRP to identify demand spikes or unplanned seasonality if this has not been considered in the underlying MPS previously. The result is again heavy expediting with negative cost effects on one side and the potential for stock outs on the other.

Lead-time ambiguity. MRP can use two different lead-time types. If the manufacturing lead-time (MLT) is used, orders are often released too late and therefore, due dates are not met. This is caused by MRP neglecting the availability of intermediate products and the current workload on the shop floor (Wijngaard, 2007). The other option is the cumulative lead-time (CLT). The concept assumes that all required components are not available, which is only infrequently true (Ptak and Smith, 2011a). Therefore, the time represents an overestimation of the real time required. This causes work orders being released too early and levels of work in progress (WIP) being unnecessarily high. Finally, the system is due to this fact only badly prepared for late order changes.

Unresponsive demand determination. MRP allows for considering forecasted demand in form of the MPS. This is possible in full or not at all. In the first case, safety stock levels are calculated and work orders are released once the safety quantity is reached. Since such safety or minimum stock levels are calculated once per planning period without regular updates this might result in high stock levels for products not needed and expediting work orders for others currently needed. If MPS data is not considered then the company switches to a pure make to order (MTO) configuration. Since this is not possible for all companies depending on the product/volume mix (Fisher, 1997), a lethal cost spiral and permanent expediting would be the result.

Lacking priority consideration. MRP considers work orders for stock replenishment, regular customer demand and past due demand as being equal. This lacking consideration of priorities requires permanent observation and analysis of work orders and production schedules and unfortunately also manual priority changes (Ptak and Smith, 2008).

On the basis of the findings made, it can be concluded that MRP is not the standard instrument shaping “the way of life in the future” (Orlicky, 1975) anymore. Ptak and Smith (2008) support this claim by arguing that “the world that existed when MRP was developed no longer exists”. Businesses are global today and have to prepare themselves for fluctuating customer demand and fierce levels of competition that did not exist 30 years ago.

It now becomes obvious that standard MRP does not really deliver what organisations in our current environment need. Based on the economic impact discussion, companies basically have two options: to live with the issues and suboptimal results standard MRP delivers or to invest in SCM software to circumvent them.

Furthermore, recent popularity of continuous improvement methodologies like lean manufacturing or TOC seem to contradict the MPS driven push methods implemented in MRP. The question comes into mind why all such well-known ERP vendors have not improved their MRP functionalities. Ptak and Smith (2011) provide an answer to this by claiming that experts in continuous improvement often do not understand the requirements of enterprise software and that those knowledgeable about MRP software development have all been retired by now. Whilst this answer might seem to be too easy and also lacking thorough depth, there must be way of upgrading the old technology up to a level that suits the demands of current manufacturing organisations. The final part of this chapter tries to develop a proper answer in form of a model that can be readily applied to practice.

2.3 TOC

The Theory of Constraints (TOC) has been introduced and developed by Eliyahu M. Goldratt since the early eighties of the last century. Ihme (2011) provides a quite intensive review of the whole theory, which should not be repeated here. Nevertheless, a brief review of the components, the history of development and elements relevant to later parts of this research are presented next concluded by an evaluation of its appropriateness to operations management and its effectiveness. The justification of picking this specific improvement methodology is formed by personal experience of the author and by pieces of literature that use it as an important component for developing a model for production planning and control.

Gupta and Boyd (2008) defined TOC as a theory relevant to operations management while Schragenheim and Dettmer (2001) emphasise the systems approach of TOC by saying that TOC is "[…] all about systems and the interaction of their component parts." Tulasi and Rao (2012) characterise TOC as a management philosophy that focuses on operations management with the overall goal of improving organisational effectiveness (Goldratt et al., 1986). They continue their description by identifying three streams or paradigms TOC today consists of. The first is called logistics by them or decision-making by Boyd and Gupta (2004), meaning a strong focus on manufacturing (Gardiner, Blackstone and Gardiner, 1994; Mabin and Balderstone, 2000) and supply chain management (SCM) (Watson and Polito, 2003). The second paradigm defines and further develops organisational performance management based on the foundations of the original throughput accounting (Goldratt and Fox, 1987). Finally, the paradigm of the thinking processes represents the all-embracing and ground-laying part of the theory (Tulasi and Rao, 2012). Spencer and Wathen (1994) cite Goldratt while stating that management has to answer three questions while improving performance:

1. What to change
2. What to change to?
3. How to cause the change?

Moreover, it links back to the first paradigm of logistics or better decision-making by providing a logical framework for system analysis.

Before discussing single areas of TOC, Table 2 presents an overview of the history and development of TOC from its origins until recent works by using categories developed and shown in Watson et al. (2007) and Miguel et al. (2010) as well as a final category representing recent trends.

Era	Timeline	Developments	Literature
Optimized Production Technology (OPT)	1979 – 1984	• OPT software • Production scheduling • Focus on improving the constraint • Nine OPT rules • Mismatch between classic performance measurement and OPT results	• Goldratt (1980) • Bylinski, 1983) • Goldratt (1988) • Fry et al. (1992)
The Goal	1984 – 1990	• Five focussing steps • Basis for the process of ongoing improvement (POOGI) • Drum-Buffer-Rope (DBR) • Focus on buffer management (time, shipping, capacity) • Continued clashes with standard performance measurement	• Goldratt and Cox (1984) • Goldratt and Fox (1986) • Umble and Srikanth (1995) • Schragenheim and Ronen (1991)
The Haystack Syndrome	1990 – 1994	• Throughput Accounting (TA) • Redefinition of classic measurement (Net Profit, Return on Investment and Cash Flow	• Goldratt (1988) • Goldratt (1990) • Cox et al. (1998) • Boyd and Cox (2002)

It’s not luck	1994 – 1997	• The Thinking Processes (TP) • Current-Reality-Tree (CRT) • Future-Reality-Tree (FRT) • Transition-Tree (TT) • Evaporating cloud (EC) • Prerequisite tree (PRT) • Logical application chain (CRT→EC→FRT→PRT→TT)	• Goldratt (1994) • Scheinkof (1999) • Schragenheim and Dettmer (2001)
Critical Chain	1997 - 2008	• Critical Chain Project Management (CCPM)	• Goldratt (1997) • Umble and Umble (2000)
TOC implementation	2008 - today	• Interoperability with other methodologies • Refinement of tools and techniques (MTO, MTA, DDMRP) • Focus on application and results	• Mabin and Balderstone (2000; 2003) • Blackstone (2001) • Schragenheim and Dettmer (2001) • Gupta (2003) • Gupta et al. (2004) • Ehie and Sheu (2005) • Ptak and Smith (2008) • Sproull (2009) • Cohen (2010) • Ptak and Smith (2011)

Table 2 – Eras of TOC development

2.3.1 TOC methodology

TOC is according to Schragenheim and Dettmer (2001) “[…] all about systems and the interaction of their component parts.” Therefore, it treats organisations as systems and not as a series of separate functions or processes. According to them, Production is usually organised as pieces of work flowing through this series of functions and across some functional or departmental boundaries. Furthermore, it often causes different degrees of optimisation or sub-optimisation because coordination of activities is often limited due to visible or even invisible barriers. In most cases, this does not result in maximising the whole system performance due to two reasons. First, functions usually operate in some form of sequence, which means that even the most capable element of this sequence cannot improve the performance of the weakest element. Second, variations in performance cause fluctuations, which in sequential operations accumulate at the last function of the process (Schragenheim and Dettmer (2001)). Thus, local maximisation will not always add up to the whole system's performance, which demands for synchronised efforts on the whole system. This could according to Deming (1993) easily mean, that some parts do not have to operate at full speed to enable a smooth flow. Schragenheim and Dettmer (2001) conclude, "The system optimum is not the sum of the local optima." Moreover, viewing a production environment as a chain of functions or processes makes it easily understandable that the system cannot perform any faster than its weakest element can do and that improving single elements except of the weakest link does not make the chain any stronger. It does not matter whether one sees manufacturing as a chain or a network of different functions or processes, there is most often only a few or even a single weakest link or element (Goldratt and Cox, 1984). They call it the system constraint, which needs to be optimised in order to improve the whole system's performance. Improving or breaking the system constraint will result in another element being the weakest link or the new system constraint. This lies at the heart of constraint theory, that constraints may wander from one place to another, but there is always one present. An advantage of this single focus for improvement has been identified by Jackson and Low (1993). They stress the value that common understanding of the importance of the constraint to the whole system's performance delivers. Organisation-wide measurement of decisions with relation to the effects on the constraint helps focussing efforts. Therefore, a constraint is defined by Goldratt and Cox (1984) as anything that limits a system from achieving a higher performance versus its goal. Since every system has at least one constraint (Rahman, 1998), there is always an opportunity for improvement.

2.3.2 Five focussing steps and POOGI

Rahman (1998) clearly identify TOC as a methodology having continuous improvement in its focus. The aforementioned central tool for establishing improvement and its continuous character are the five focussing step explained in Goldratt (1990a).

Identify the constraint. The first step is the identification of constraints being physical or managerial in their nature. Goldratt (1990a) continues by stating that organisations generally only have a few physical constraints but many managerial ones in form of policies, procedures, rules and methods. The importance of this first step is described by Goodrich (2008) in her own words: "Constraint identification is an important necessity, because constraints impact on business goals". This is perfectly in line with Rahman's (1998) constraint improvement statement mentioned earlier. However, Srikanth and Umble (1997) are cautious when stating that this is not always a straightforward activity. An ideal tool for finding such constraints is the CRT resulting from the thinking processes described later.

Exploit the constraint. Depending on the nature of the previously identified constraint, different actions are appropriate. If the constraint is physical then the goal is to make it as effective as possible. Maybe, there is a chance of breaking it with minimal resources and re-entering the cycle at the first stage (Schragenheim and Dettmer, 2001). In case of managerial constraints, exploiting them seems not to be the most suitable measure (Rahman, 1998). He suggests eliminating it and replacing it by a policy that has the potential of increasing flow and throughput.

Subordinate everything to the constraint. Since the performance of the constraint determines the performance of the overall system (Rahman, 1998), subordinating all non-constraints in order to maximise the effectiveness of the constraint is sought. This subordination often results in adjustments made to non-constraint resources. They provide two forms of capacity productive (supporting the throughput of the constraint) and non-productive (excess capacity representing a protection against disruptions and such not needed at all) (Lockamy and Cox, 1994). The latter form of capacity of non-constraints could be used in a positive way by establishing buffers of spare capacity (Srikanth, 2010) or in a negative way by simply heading for local optima and producing unnecessarily high levels of WIP (Schragenheim and Dettmer, 2001).

Elevate the constraint. This step needs to verify the validity of the initial determination of the system constraint. According to Schragenheim and Dettmer (2001), it might be possible that the output of the constraint has been increased up to a level where other former non-constraints are now likely candidates for being the new system constraint. If this is the case then reentering the cycle at the first stage is the obvious way to continue.

Prevent inertia from becoming the constraint. Whether the previous step has broken the constraint or not, going back to the first step seems valuable and emphasizes the continuous character of the tool. Independently of a decision made to leave the constraint where it is or not, verifying that the constraint has not moved or identifying where the new constraint is, represents the starting point for a new iteration. The warning to beware of inertia has been added by Goldratt (1988a) for two reasons. First, to evaluate if decisions made in the second and third stage were appropriate for the constraint in focus. Since the constraint could have moved caused by actions in the previous stages, they might not be appropriate for the new constraint anymore. Second, mentality or organizational culture often causes people to think once a solution to a problem is proven to be successful the problem might never occur again. Goldratt and Cox (1984) as well as Jacob et al. (2010) have shown that this might not be the truth.

The following Figure 4 summarizes the five focusing steps shown as a process of on-going improvement.

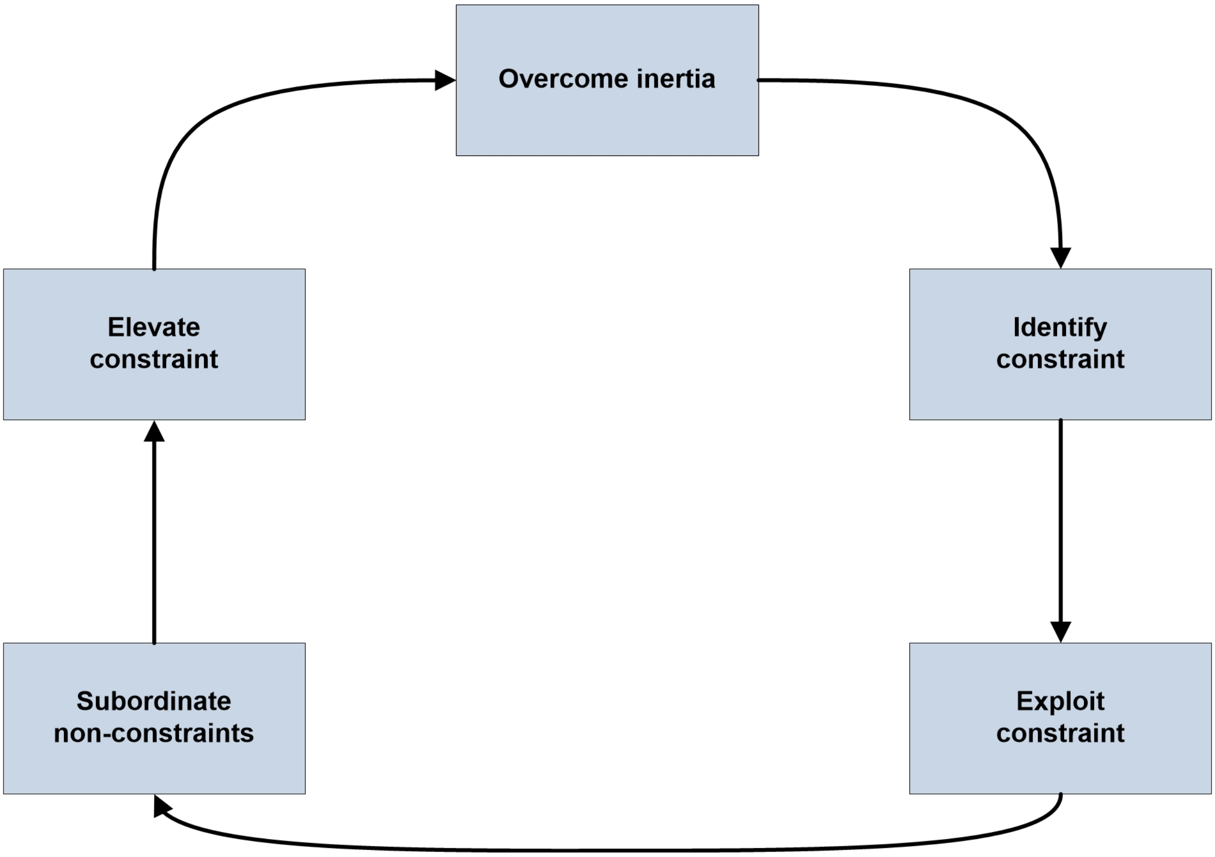

Figure 4 – Process of on-going improvement

The five focussing steps described previously fulfil all criteria for being a process of on-going improvement by including re-iteration and continuous evaluation of decisions being made earlier (Mabin, 1999). This recurring review of the whole system underlines the importance of seeing the big picture as in a systems approach suggested by Goldratt et al. (2000) in line with Michalski (2000). Goodrich (2008) advocates for taking this circular perspective instead of linear outlooks. This perspective is likely to result in a complex web of interrelationships within the system observed (Mabin and Balderstone, 2003). The constraint is then seen as a part of the whole in its context being interrelated to a specific outcome.

2.3.3 TOC performance measurement and accounting

Following the theme of the last section, a systems perspective requires adequate ways of performance measurement (Mabin and Balderstone, 2003). They continue with the requirement for measurement to be global rather than being locally and efficiency focussed to avoid any form of misalignment reported by Corbett (1998) or Smith (2000). Traditional management accounting measures often the three figures of net profit (NP), return on investment (ROI) and cash flow (CF). Schragenheim and Dettmer (2001) criticise the concentration on this measures since they are not transparent to shop floor managers being responsible for daily decision-making. Especially, the effect of local decision on the organisational performance is hardly visible. Since TOC cannot ignore the prominence of these three performance indices, they are kept enriched by three operational measures of throughput (T), inventory or investment (I) and operating expense (OE) that are related back to the traditional figures (Goldratt, 1990), alleviating Schragenheim and Dettmer's (2001) critique. He defines throughput as the transformation of things coming into the company (i.e. raw material) into something of value for the customer (i.e. finished goods). It represents the value of sales less the truly variable costs, which means that labour is not included in the variable cost here. Investment or inventory is defined as all the money invested into things that are used to generate throughput. This might include things such as fixed assets, raw materials and equipment. Finally, operating expense represents the remaining cost not deducted from sales to determine throughput. Among those one could find overheads (i.e. General&Administrative), direct and indirect labour. As already mentioned, this deviation from classic cost accounting is intended to show costs here that are paid for anyway (e.g. monthly salaries, complete shifts that have been ordered, …). Schragenheim and Dettmer (2001) together with Mabin and Balderstone (2003) identify the strength of this approach by having simplicity and direct relation to workplace decisions in form of the three operation measures and a clear relationship to standard performance measurement used by top management. Looking at the relations of standard figures to the TOC definitions makes it easier to understand the underlying idea.

$$Net\ Profit = T - OE$$

$$ROI = \frac{T-OE}{I}$$

$$CF = T - OE \pm I$$

Now it becomes easy to understand for everybody, that increasing throughput while leaving the other two measures constant or trying to decrease their value has positive contributions to NP and ROI, leaving timing issues aside.

Another prove of how embedded these accounting principle are in TOC can be found while analyzing the relationship between the three measures of T, I and OE and the five focusing steps. T is addressed in all steps since they focus on the constraint and on how to improve the throughput of the overall system by finding and exploiting it. Following this, subordinating everything else under it and verifying the level of improvement are also intended to protect and improve throughput. Finally, preventing inertia from becoming the constraint is also directed towards protecting the achievements made and for encouraging the continuous character of throughput improvement initiatives. Inventory (I) is mainly addressed in the third focusing step by subordinating everything under the constraint. Unproductive capacity that mainly results in unnecessarily high levels of WIP or that is intended to focus on achieving local optima is classified as waste that should be removed from the system. The remaining measure of operating expenses (OE) is not directly mentioned in the five focusing steps. Goldratt (1990) sees these costs as overheads one has to accept as being prerequisites of running an operation. Since they are non-variable in their nature and presumably harder to influence, they have been left out of the focus of the improvement cycle. Gupta et al. (2002) support this view by reporting improved throughput and reduced inventory figures and leaving OE constant over the time of the simulation undertaken.

Goldratt et al. (2000) continued the development of TA by coming back to the two measures of throughput dollar days (TDD) being things done behind schedule and inventory dollar days (IDD) being things done ahead of schedule, which have been mentioned in previous publications as Mabin and Balderstone (2003), Gupta and Anderson (2012) or Sale and Sale (2013). They are defined following a common theme of using the value of ordered throughput or inventory held respectively times the amount of days. The definition is based on the assumption that a dollar day means the value of holding one dollar for one day and is shown next:

$$TDD = (unit\ cost) * (ordered\ quantity) * (days\ late)$$
$$IDD = (unit\ cost) * (quantity\ on\ hand) * (days\ in\ the\ system)$$

It becomes obvious that these operational measures are useful for determining the performance of a supply chain in a way that is easily understandable for almost everybody. They are designed to make operational and design decisions in relation to the strategic goal of maximizing ROI (Smith, 2000). TDD measures the time value of orders that could not be shipped due to material shortages. In an ideal world the value should be zero since there should be no late orders. IDD measures excess inventories be assigning a time-based value to the cost of being ready too early. It becomes clear that holding excess inventories comes at a cost. Although, buffers mentioned earlier are most often part of the whole system design, close control of the value makes sense in order to maximize ROI. However, an IDD value of zero is expected to happen only in rare cases being strongly influenced by product, customer expectations and markets.

2.3.4 TOC thinking processes

In a previous section, the TOC characteristic of providing a POOGI leads nicely to a review of the thinking processes (Gupta, 2003). Rahman (1998) identifies that applying the five focussing steps on physical constraints might lead to shifting the constraint to the market, which is rather a managerial or policy constraint than a physical one. Such non-physical constraints are quite often the main constraint a company is facing (Rand, 2000). The thinking processes are ideally suitable for finding factors that prevent the system from achieving its goals pretty much in the same way as the five focussing steps concentrate on the constraint (Tulasi and Rao, 2012). They do this by trying to find answers to Goldratt's (1984) three generic managerial questions of what to change, what to change to and how to cause the change (Kim et al., 2008). This is done by applying cause-and-effect logic to identify sufficiency and necessary condition logic to validate findings (Mabin, 1999).

Tulasi and Rao (2012) define the thinking processes as a set of trees or logic diagrams that form a road map for change. (Mabin and Balderstone, 2003) say, that they are a "suite of five logic-based tools which allow managers to analyse problematic situations and to identify, enhance and implement win-win solutions appropriate to the situation". The concept, which Noreen et al. (1995) call "[…] the most important intellectual achievement since the invention of calculus" should become clearer while discussing the specific tools briefly. The following Table 3 provides linkages between the generic questions, their purpose, the tools to be used and their underlying type of logic. The content and design have been influenced by Rahman (1998), Mabin (1999) and Watson et al. (2007).

Generic question	Purpose	TP tools	Type of logic	Literature
What to change?	Identify core problems	• Current Reality Tree (CRT)	• Cause-and-effect	• Goldratt (1990a) • Dettmer (2007) • Button (1999) • Button (2000)
What to change to?	Develop simple and practical solutions	• Evaporating Cloud (EC) • Future Reality Tree (FRT)	• Necessary condition • Cause-and-effect	• Goldratt (1990a) • Dettmer (2003) • Dettmer (2007) • Goldratt (1990a) • Balderstone (1999) • Smith (2000)
How to cause the change?	Implement solutions	• Prerequisite Tree (PRT) • Transition Tree (TT)	• Necessary condition • Cause-and-effect	• Goldratt (1990a) • Klein and DeBruine (1995) • Goldratt (1990a) • Klein and DeBruine (1995) • Dettmer (2007)

Table 3 – TP tools and roles

Current Reality Tree (CRT)

Goldratt (1990a) calls an existing condition in a system a reality. CRT focuses on realities with which a problem solver is not satisfied (Tulasi and Rao, 2012). It does so by creating a picture of the current reality in a system in focus (Dettmer, 2007). It is expected to deliver the most probable chain of cause and effect under a fixed set of circumstances (Mabin, 1999). She continues her description by pointing out that its design follows a top-down approach from observed undesirable effects (UDE) to assumed causes for such effects. Those postulated causes are then tested by using Goldratt's Categories of Legitimate Reservation (CLR) that are a set of guidelines for analysing any concerns related to the elements and connections (Balderstone, 1999; Dettmer, 2007). According to Mabin (1999) a CRT serves the following purposes:

- Effective testing of new ideas
- Evaluation if proposed changes will provide the desired effects
- Identification of any negative effects decisions might have on other parts of the system
- Means of initial planning and persuasion

Evaporating Cloud (EC)

After having identified what to change, the next step is to develop a possible solution to the root cause; what to change to (Mabin, 1999). The EC is designed to help the practitioner with this task by introducing a set of five boxes. First, one needs to identify two opposing wants that represent the conflict and their related needs they are trying to satisfy. Both chains represent the conflict as they are trying to fulfil the same common objective. Once the diagram is constructed, one starts with analysing the connections between the common objective and the needs, the needs and wants and by this arrives at the reason for the conflict that prevents both chains from achieving their desired objective (Tulasi and Rao, 2012). The conflict is then resolved by assessing underlying assumptions or prerequisites in order to develop injections that can break anyone of the assumptions and by this remove the problem. Dettmer (2007) lists the main purposes of an EC:

- Confirmation of an existing conflict
- Resolve the conflict
- Create win-win solutions
- Provide explanation of a conflict and any underlying assumptions

Future Reality Tree (FRT)

This next step of the chain of TP tools assumes that a solution in form of the injection identified has been implemented (Mabin, 1999). The construction of the FRT represents the future solution on the basis of cause-and-effect logic that is tested step by step. The main role is to identify what to change and to check for each step if negative branch effects or overlooked side effects might appear. The resulting tree begins with injections and finishes with desirable effects. It therefore represents the next logical step after the CRT, because it connects causes with injections and arrives at desirable effects. Goldratt's CLR guidelines are suggested to be used in order to show validity of the findings made (Balderstone, 1999). Tulasi and Rao (2012) summarise the main characteristics, which are similar to those of the CRT due to its comparable design:

- Effective testing of new ideas
- Evaluation if proposed changes will provide the desired effects
- Identification of any negative effects decisions might have on other parts of the system
- Means of initial planning and persuasion

Prerequisites Tree (PRT)

Gupta (2003) describes the role of a PRT as identification of any obstacles to the implementation of new ideas and the determination of intermediate objectives to overcome them. The importance of uncovering and eliminating such obstacles since an idea is not a solution until it is fully implemented and working as intended (Goldratt, 1990a). However, not all ideas require the construction of a PRT, as Dettmer (2007) notes. He suggests PRTs being useful for complex situations and when a detailed route to establish the solution is not clear at the outset. He summarises the functions of PRTs as:

- Identification of any obstacles preventing implementation of the solution
- Determination of means to overcome obstacles
- Definition of a sequence of tasks or actions needed

Transition Tree (TT)

This represents the last step of the chain of TP tools. The role of TTs is the determination of actions necessary to implement the solution (Klein and DeBruine, 1995). It uses effect-cause-effect logic to develop and verify the implementation plan (Mabin, 1999). Dettmer (2007) while comparing FRTs and TTs says that the role of FRTs is a strategic tool to outline the changes required while a TT is a more tactical tool containing more detail relevant to the implementation. He describes the structure of a TT as having four or five distinct elements in a fixed order. It starts with a condition of existing reality, links it to an unfulfilled need, continues with a specific action to be taken and finished with an expected effect. In some situation where support from other parts or higher hierarchy levels of the organisation is needed, the fifth element provides a rationale for the need in focus. Again, elements from Dettmer's (2007) summary of the objectives of TTs are shown overleaf:

- Step by step guide for implementation
- Provision of navigation and identification of any deviations
- Communication of reasons for actions

- Execution of injections developed in the EC or FRT
- Achieving intermediate objectives of the PRT
- Provision of tactical plans in relation to strategic objectives

Figure 5 provides the full picture of the sequence of tools. It uses iconic figures of each tool published in FlyingLogic (2007) and is inspired by a comparable figure from Watson et al. (2007).

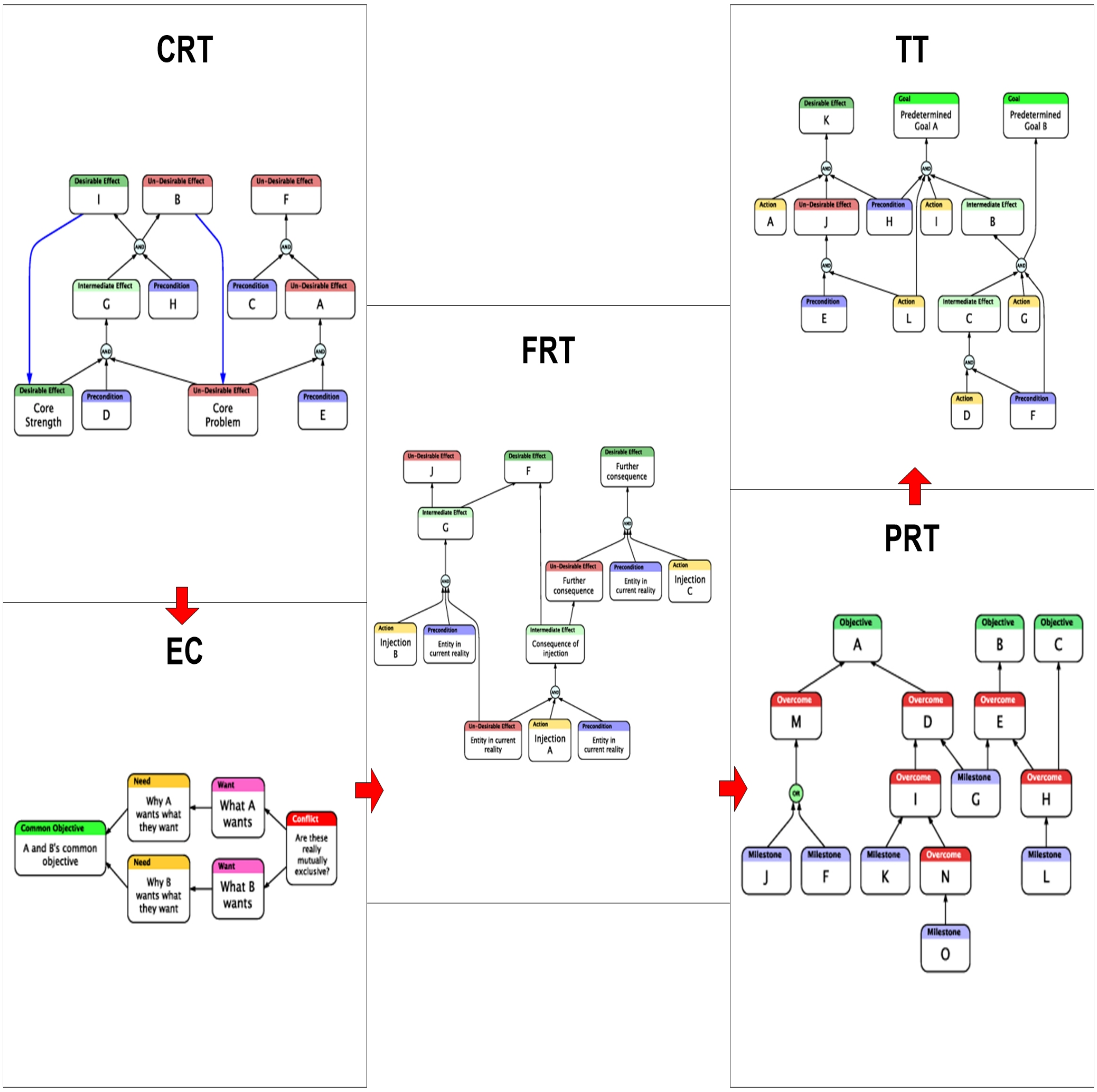

Figure 5 – TOC thinking process tools

2.3.5 TOC in manufacturing

This research has the development of a model for high performance production planning and control in focus. This focus places the area to select concept from right in the middle between standard S&OP and MPS development having a longer time in focus and shop floor management with concepts like DBR or S-DBR paying attention to the shorter time periods. This view is not only supported by experience of the author but also by an understanding shared with Schragenheim et al. (2009) and Cohen (2010). For accounts on the former more strategic levels, Ptak and Smith (2011) can provide more insights and for the latter more tactical or even micro-tactical or operational levels, Ihme (2011) provides a comprehensive review. The short to medium time focus leads to the area of productions and operations management that is influenced by the three main factors of the modes of supply within the supply chain, capacity profiles and the production flow (Cohen, 2010). Each of the three areas is now dealt with in turn.

Modes of supply

In a manufacturing company, the production facility is one element of the supply chain that links upstream to raw material procurement and storage and downstream to the warehouse and to shipment to customers (Mentzer et al., 2001). The performance of the production and the link to the next part of the supply chain determines quite often the performance of the whole company, since it means the ability of the company to generate cash through sales that is clearly affected by the ability to ship on time (Cohen, 2010). Figure 6 adapted from Cohen (2010) shows the situation.

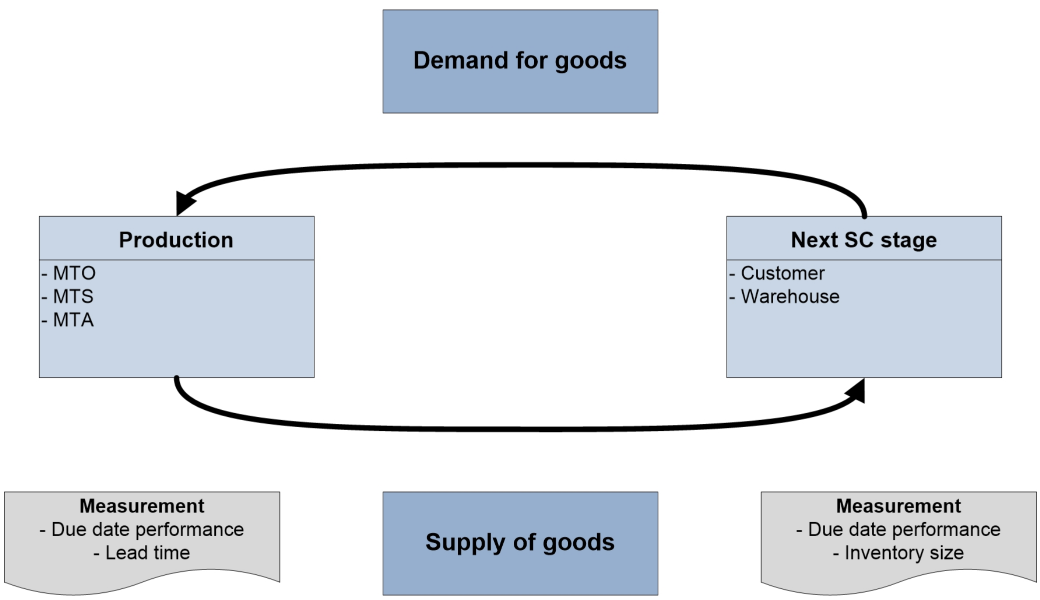

Figure 6 – Relationship between production and logistics (source: Cohen, 2010)

There are two conventional modes of supply being MTO and MTS (Vollman et al., 1997). In a MTO environment, the next link represents the customer via the shipping process. For each production order there is a directly related purchase order from the customer containing specific goods, required quantities and due dates. There are different forms of due date fixing depending on the industry and specific customer relationships varying from individual negotiation until fixed agreements. Once the order is agreed it represents a contract between both parties that the production simply needs to fulfil (Cohen, 2010). According to him, this is an ideal situation for production once the response time (including production time) is achievable and accepted. The fundamental difference between the former and MTS environments is that production is not based on firm orders. It is therefore the decision of management to produce influenced by availability commitments to customers and experience in form of forecasts (Vollman et al., 1997). Quite often, the lead-time between arrival of customer orders and shipment is expected to be shorter than in MTO environments (Cohen, 2010). Other reasons for operating MTS is the sheer amount of products available in relation to the available production facilities or small order quantities in comparison with minimum batch sizes (Fisher, 1997; Hopp, 2008). Cohen (2010) summarises the main motivation of MTS as “building strategic stock for future consumption”. The third mode of supply is MTA, which is a TOC derived improvement method for MTS environments first developed by Schragenheim et al. (2009) and further refined by Cohen (2010). In contrast to standard MTS where production is initiated on the basis of forecasts or knowledge about future trends (e.g. seasonality), MTA is based on a more direct link between actual consumption and production decisions. Whilst under MTS stock levels are only monitored by defining minimum and maximum levels, MTA suggests a closer monitoring based on buffer levels.

Schragenheim et al. (2009) and Cohen (2010) stress the fact that production environments are often characterised by mixtures of MTO and MTS or MTA respectively. They argue that the variety of products and the related product/volume mix (Fisher, 1997) triggers such developments where high volume or seasonal products are made to stock and “low-runners” or configured products are made to order. Altogether, the mode of supply’s main objective is to fulfil the needs of the next link in the supply chain.

Capacity profiles

The influence of capacity is enormous on the results of the production function, since it has to be managed due to various reasons as multiple finished product demands, needs for intermediate products, limited availability of machinery and conflicts arising from fluctuating levels of demand (Hopp, 2008). Capacity is defined as the amount of time a machine or resource is available for performing manufacturing operations (Cohen, 2010). It is determined by the amount of days and shifts available, the amount of workers or operators available and the up-time of a resource. Once the available time is known it needs to be further divided into process time (resource is producing), setup time (resource preparation) and idle time (resource is not used). It becomes obvious that the available capacity has a strong and direct influence on production lead-time (PLT) and with this on the ability to complete work orders on time. In TOC one considers three different types of resources in relation to their capacity utilisation: bottlenecks, critical constraint resources (CCR) and non-CCR. The latter is defined as a machine when its idle time or protective capacity in TOC terms is more than 30% of its available capacity. A machine becomes a CCR when its protective capacity is less than 30%, which requires close monitoring since it might be the reason for deviations from the plan. A special form of CCR is the bottleneck. This resource has no protective capacity at all and represents therefore a critical factor directly affecting production performance. Any problems on a bottleneck cause disruptions to the overall flow, which often means delayed work orders and growing queues of WIP in front of the bottleneck. Cohen (2010) describes the CCR as a potential headache and the bottleneck as a nightmare to production managers.

Buffer management

Buffer management is the monitoring or diagnostic part of the TOC replenishment solutions that serves as an alarm system that indicate serious and urgent problems, provides control on lead-time and indicates weak areas on the shop floor that are likely candidates for improvement (Schragenheim and Ronen, 1991). This definition is perfectly in line with Sullivan et al. (2007) who explain buffer management as “a feedback mechanism [..] that provides a means to prioritize work, to know when to expedite, to identify where protective capacity is insufficient and to resize buffers when needed”.

In practice buffer management represents monitoring of the inventory in front of the protected resource and comparing reality with the plan (Schragenheim and Ronen, 1991). Buffers have been described by them as consisting of three equal fractions of time or zones being green, yellow and red. These represent the different modes of attention, a buffer manager needs to adopt according to the buffer time left until processing is scheduled. Green means no attention, yellow triggers locating the missing part and reminding the current location to maintain the schedule and red demands for expediting the part between the current location and the constraint in order to protect its operation (Blackstone, 2010). More recent literature as Tseng and Wu (2006) or Cohen (2010) has introduced two additional zones. These are black for parts that should have been completed and are now overdue and white or light blue for orders that should not have been released by now.

Schragenheim and Ronen (1991) define the three distinct buffers being constraint, shipping and assembly buffers. The first is a time buffer installed to protect the constraints operation and schedule. It is defined in units of time and represents one part of the overall manufacturing lead-time (Blackstone, 2010). The second buffer is the shipping buffer, which cannot be easily measured in units of time since it has no explicit processing time. It is also defined by a total number of hours being divided into three equal zones, but here the number of units to be shipped is monitored against plan. Finally, the assembly buffer is defined in a similar way as the shipping buffer. It has also no own processing time but monitors the arrival of all parts according to the assembly schedule. Fry et al. (1991) and Blackstone (2010) stress that in serial line manufacturing with a singly constraint operation there should be only a constraint and a shipping buffer. The resulting manufacturing lead-time represents the sum of both buffers. The introduction of an additional assembly buffer makes only sense if there is a non-constraint assembly that uses constraint and non-constraint parts and one of the non-constraint parts has a longer lead-time to the assembly than the constraint parts. In such case, Blackstone (2010) suggests the lead-time to be the sum of the assembly buffer and the shipping buffer.

After having explained the concept of buffer management, the task of sizing needs to be dealt with. Blackstone (2010) cites Goldratt's suggestion to take one half of the current manufacturing lead-time and dividing this between the constraint and the shipping buffer. This should act as a starting point and needs continues monitoring and adjustment according to the number of expedited jobs. While some researchers are almost in line with this suggestion using quite simple empirical rules (Srikanth and Umble, 1997; Louw and Page, 2004) others as Weiss (1999), Gonzales-R et al. (2010) and Lee et al. (2010) favouring more sophisticated and context-sensitive approaches. However, all agree that one needs to start somewhere and that regular monitoring of adequateness and fit is required to identify areas of improvement.

TOC solution for MTO

Cohen (2010) characterises MTO environments with the identification of the need to provide the customer with quality products at acceptable prices with high delivery service levels. That is his main reason for setting due date performance improvements as a first and major target. However, this should not be interpreted in a way that other performance criteria as investment or operating expenses can be neglected. Following the TOC performance measurement, maximisation of throughput is goal number one, which surely is supported by delivering products on time.

By following the hierarchy of managerial decision making from strategy over tactics down to operational levels, Cohen (2010) identifies a high level of due date performance of ideally greater than 99% at the strategic level as the goal. At the next level of tactics, the implementation of S-DBR and buffer management should be sufficient steps supporting the achievement of the strategic goal (see Ihme (2011) for a full description). At the operational level, Cohen (2010) specifies three groups of injections being necessary for achieving the tactical goals being mindset, immediate improvements of DDP and continuous improvement (POOGI). The strategic goal of high DDP requires an adequate thinking and decision-making process throughout the whole production function that customer orders are the major driver for managing the production. This mindset needs not only to be introduced but also continuously enforced to overcome inertia. The second group of injections focuses on immediate improvement of the DDP measure in direct support of the strategic goal. Cohen's (2010) suggests the following four measures:

- The introduction of buffer management has created the production buffer, which should be set to a challenging but also achievable level. Production orders are then released accordingly.
- Buffer management has created buffers for each customer order. The related open production orders managed and prioritized according to the buffer status of the customer order.
- Since even best practices suggested by the previous two measures cannot guarantee high levels of flow and smooth running of production orders, a structured way of expediting needs to be incorporated into working practices.

- Identification of raw materials or components that are critical factors determining the flow through the production helps to establish an adequate monitoring of their availability. This further requires the development of an understanding why these items are problematic and taking adequate actions (e.g. replenishment type (customer order specific, forecast-orientated, to stock)).

Having now demonstrated that DDP can be improved by the implementation of the previous five injections, sustaining the improvement and even further increase the performance is sought. According to Cohen (2010), this can be done by implementing continuous improvement on the tactics level supported by three injections on the operational level. Having set suitable buffers at the production (CCR) and the procurement side does not mean that further improvement is not possible. Moreover, structured management of recovery actions has been identified to be supportive for stabilising the system, once buffers are getting too long. Cohen (2010) summarises the potential: “The shorter the (time) buffer or the smaller the (stock) buffer, the higher the performance of the system […] can be.” The three injections are presented briefly next.

- Regular monitoring of the penetration reasons of the production buffers for critical production orders is established to identify common reasons. These are then analysed and improved by employing various techniques originating from popular improvement methodologies as lean manufacturing or Six Sigma.
- Although S-DBR assumes that there is no bottleneck in the system except for the market (Schragenheim and Dettmer, 2001), there are situations when lacking available capacity at some machines causes queues to build up in front of them. This causes buffer penetration that is then treated with recovery actions in order to maintain high DDP. Cohen (2010) suggests monitoring of such temporary bottlenecks to be able to foresee them and to take corrective actions in cases of frequent occurrences (e.g. installing more capacity).
- Sproull and Nelson (2012) provide practical examples of the need to size batches appropriately in order to avoid unnecessarily long production lead-times. Cohen (2010) suggests that regular analysis of transfer batch sizes and their adjustment should be part of the POOGI part of the MTO solution. The reason for this is the destabilizing effect of such actions on the system that is better dealt with once buffer management is in place.

The described TOC solution for MTO is only a template that needs to be adapted to specific environments to allow for full benefit. Cohen (2010) concludes his views by pointing to hundreds of published cases where TOC MTO has achieved high levels of DDP in only short periods of time. Figure 7 is influenced by Cohen (2010) and summarises the solution by showing the mentioned levels of application.

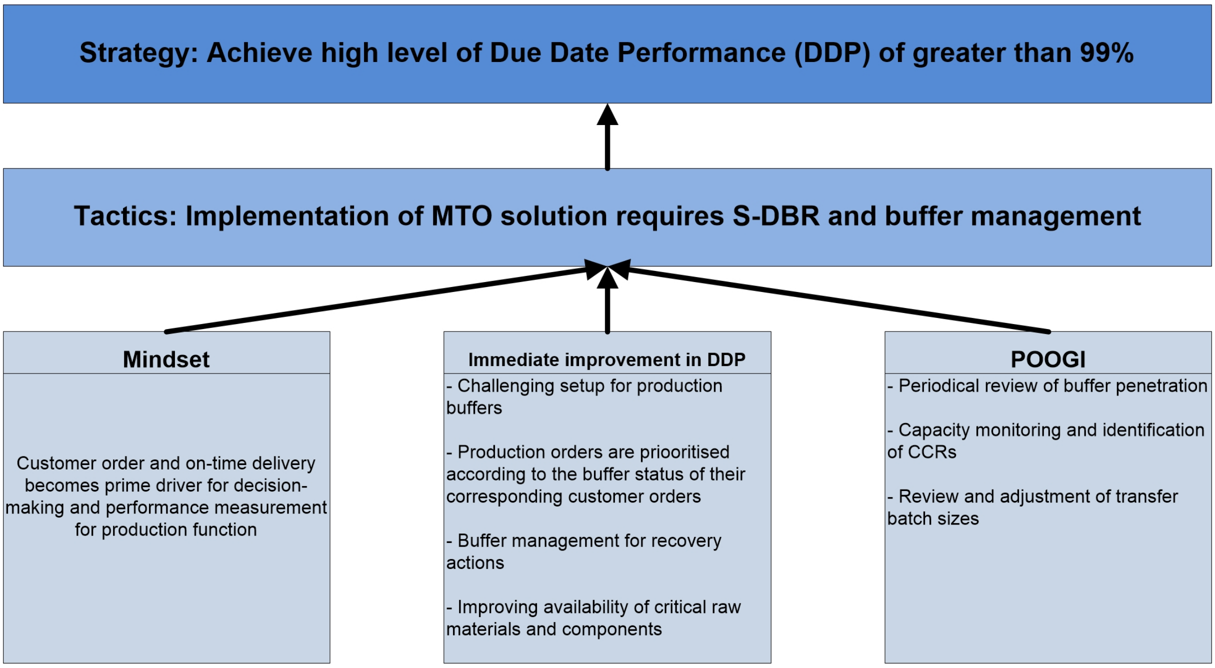

Figure 7 - TOC solution for MTO (source: Cohen, 2010)

TOC solution MTA

The previous section discussed the TOC solution for MTO environments characterised by specific customer orders being the trigger for production orders. There are cases where companies are facing customers requiring very short times between ordering and due dates that make it impossible to produce to order or the sheer amount of unique products to be sold in comparison to the machinery available makes stock a requirement. This is classified as an MTS environment where production orders are processed in absence of specific customer orders. The basis for deciding what to produce and when are forecasts and individual experience that is often codified in MRP configurations (Ptak and Smith, 2011). Goldratt et al. (2009) and Cohen (2010) are in line that the ability to correctly predict the amount of future consumption is at least limited, two major UDEs arise: shortages and excess stock. The TOC solution for MTS environments is MTA, which addresses these UDEs by establishing a strong committing on ensuring availability of parts, components and finished goods “while continuously monitoring stock levels to control and eliminate over-stocking” (Cohen, 2010).

This is done by creating a finished goods stock as a buffer protecting the sales function. This buffer is closely managed and changes its status depending on consumption and replenishment. Accordingly, the central role of the forecast in MTS environments is replaced by real demand in the MTA solution (Schragenheim, 2010).

Cohen (2010) follows the hierarchy of managerial decision making from strategy over tactics down to operational levels. He identifies a high level of availability of ideally close to 100% without holding excess inventory at the strategic level as the goal. At the next level of tactics, the implementation of the TOC replenishment system is intended to support achievement of the strategic goal. At the operational level, Cohen (2010) specifies three groups of injections being necessary for achieving the tactical goal being mindset, immediate improvements of availability and continuous improvement (POOGI). The strategic goal of high availability requires an adequate thinking and decision-making process throughout the whole production function that places the buffer states of the warehouse as the triggering and guiding force for any decision. This mindset needs not only to be introduced but also continuously enforced to overcome inertia. The second group of injections focuses on immediate improvement of availability in direct support of the strategic goal. Cohen (2010) suggests the following four measures:

- Buffers for finished goods are created at the warehouse in order to monitor availability. Production orders are triggered based on consumption of finished goods or their buffer status respectively.
- Buffer management has created buffers for each finished good. The related open production orders managed and prioritized according to their buffer status.
- Even the best practices of buffer management are prone to material shortages or machinery breakdowns. An awareness of these facts demands for a structured way of reacting to any form of disruption by introducing close monitoring of critical buffer states.
- The procurement function is responsible for providing availability of most if not all raw materials or components that are supplied by external companies. Their availability is critically important to the flow through the production. Establishing an adequate monitoring of their availability is therefore a crucial activity.

Cohen (2010) describes the third group of injections to be similar to the ones already described in the previous section on MTO.

The TOC MTA solution is suitable for many companies that see a commercial potential to hold stock of finished goods readily available at the warehouse. The main dilemma is the question of how much stock to hold for each finished product. High levels of inventory are an adequate measure of preventing stock-outs and enabling higher levels of sales. Unfortunately, this comes at the cost of producing and holding it and even losing it in case of shelf life issues. Determination of adequate stock levels is often based on the unreliable basis of forecasts or historic sales levels. MTA introduces individual buffers for each finished good at the warehouse, which are monitored and managed. The trigger for production orders is consumption in form of shipped goods that reduces the buffer status at the warehouse. This integration of production and warehouse into one replenishment system is seen as the key for improvement (Cohen, 2010). The central figure of buffer status shapes decision-making and provides the priorities for production and flow. Figure 8 summarises the concept on the basis of Cohen (2010) to enable easy comparison with the previously described concept of MTO.

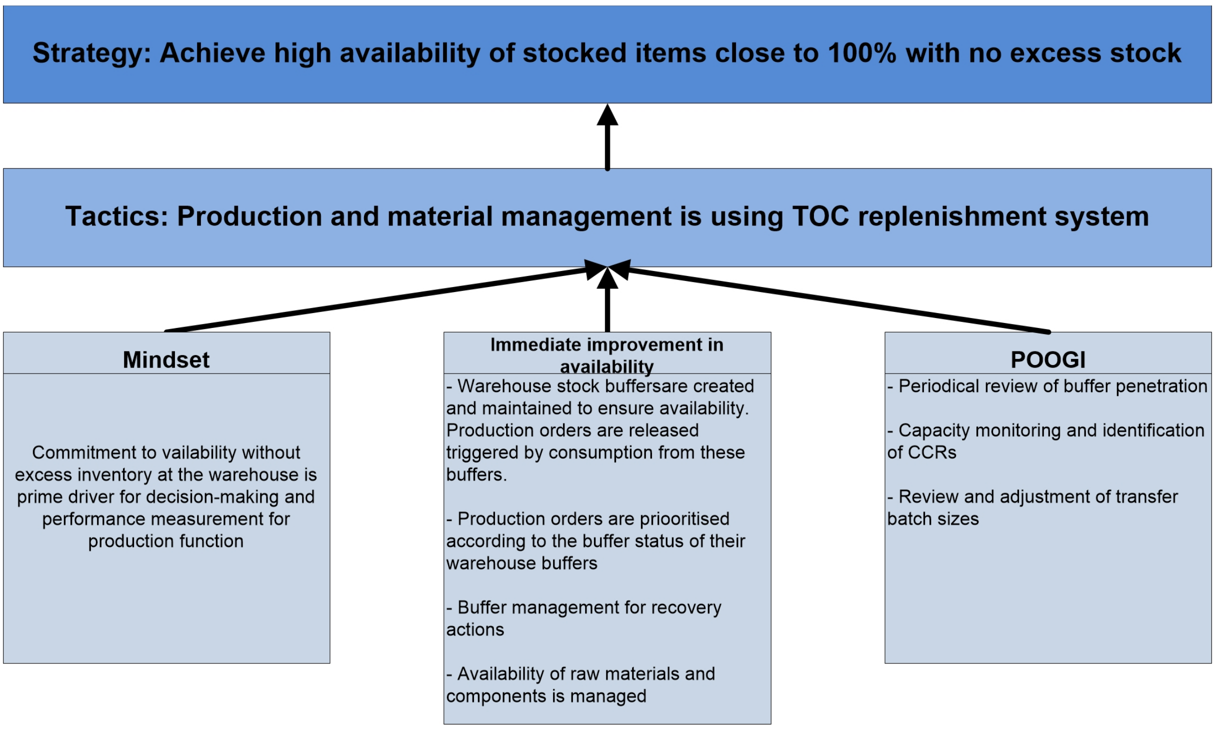

Figure 8 – TOC solution MTA (source: Cohen, 2010)

2.3.6 Evaluation

The previous sections have discussed the theory of constraints, its development and its three paradigms of logistics, thinking processes and performance measurement. A final part has set special focus on the logistics part in order to provide material relevant to the main purpose of this research. Tulasi and Rao (2012) have concluded their research by characterising TOC as “an effective, systematic approach for identifying constraints to the overall business” that also helps to alleviate these constraints. Gupta and Boyd (2008) have tested TOC with the goal to determine its quality from an academic standpoint and arrived at a good result. However, TOC has been developed to improve results in practice (Goldratt, 1980; Goldratt, 1984) and hence its value in form of its potential to improve a firm’s performance should be placed into the centre of this evaluation.

Logistics paradigm. According to Mabin and Balderstone (2003) most evidence of TOC applications can be found in the manufacturing area. Another research by the authors (Balderstone and Mabin, 1998) has also reported application of TOC in non-manufacturing and service organisations. Both findings are in line with a more recent study published by Inman et al. (2009). Mabin and Balderstone (2003) have found in a literature comparison that a huge extent of companies applying TOC to manufacturing achieved improvements of lead-times, cycle times, DDP and inventory levels. Frazier and Reyes (2000) and Umble and Umble (2001) report similar findings in the area of WIP reduction and DDP improvements. A smaller but still significant extent of the cases also reported improved financial results.

Global performance measurement. In absence of results from comparisons of many cases, single occurrences are used to provide evidence. Inman et al. (2009) found similar evidence for the beneficial effect of TOC performance measurement to organisations as for applications from the logistics paradigm. Mehra et al (2005) compared traditional cost accounting with the TOC way in a chemical firm concluding with significant performance advantages for the TOC system. Westra et al. (1996) found that using TOC performance measurement has changed the way a business set its priorities in a favourable way.

Thinking process paradigm. Among the many examples of literature concentrating on the performance of the application of the thinking processes, Chaudhari and Mukhopadhyay (2003) needs to be mentioned. They found evidence of a company using the thinking processes for problem analysis leading to improved throughput and lower inventory levels.

Scoggin et al. (2003) report a firm that used the thinking processes successfully to assist a major change initiative. Noreen et al. (1995) found successful applications of the thinking processes in several manufacturing companies.

Full implementation. Spencer (2000) reports a firm that implemented all parts of TOC to develop and establish a successful continuous improvement process. Furthermore, Inman et al. (2009) found that companies that have implemented all parts of TOC show significant improvements in form of increased levels of throughput and lower levels of inventory and operating expenses. Ihme (2013) found among hundreds of American manufacturing companies that continuous improvement methodologies show better results when used in combination with TOC. Furthermore, Sale and Inman (2003) found in a comparison of TOC, JIT and traditional manufacturing that TOC is the superior mode of operation yielding significantly higher levels of performance.

Beside this overwhelmingly positive findings regarding the potential of TOC applications to improve organisational performance, one should consider Mabin and Balderstone's (2003) warning that most studies have focussed on the short-term. This means that support for immediate improvement effect could be found in many papers including their study and Noreen et al. (1995), information about the long-term is missing in absence of longitudinal studies.

2.5 Integration of ERP/MRP and TOC

The first part of this chapter identified the prevalence of ERP systems in manufacturing companies today. Although permanent development from MRP over MRP II until ERP has led to strong integration of the majority of departments and functions into such systems, their production planning and control component is still based on developments made during the 1970s in form of the MRP technique. The evaluation of its strength and weaknesses showed main flaws becoming more and more evident due to dramatically changed business circumstances from the 1970s until today's reality. Nevertheless, companies continue to invest in ERP technology but need to face limited performance improvements resulting from such investments except combined with SCM systems.

A second part reviewed the popular operations management philosophy of TOC. It showed its beneficial effects on firm performance in general and highlighted a dominating extent of application in the manufacturing function. Among the many examples of successful applications, major improvements in the area of DDP, lead-time and inventory reductions could be found. However, the main evidence for success has to be drawn from case studies or single company investigations focussing on short-term improvements.

When comparing both frameworks, some major differences come into focus. MRP is a push-based system focussing on local efficiencies and maximisation of output (Miltenburg, 1997) while TOC with its pull-based logic tries to relate material movement, production order sizes and their releases to actual demand. Furthermore, MRP believes that the ideal plant is balanced to a degree that all work centres have the same output potential (Fogarty, Blackstone and Hoffman, 1990) while TOC explicitly accepts the fact that such plants simply do not exist in reality (Goldratt, 1991; Cook, 1994). Taylor (2002) supports this by stating that work centres are having different levels of production potential and the one with the least is the system constraint. A detailed comparison of both concepts is intended to provide an answer to the question if both systems can or should co-exist in a single environment and if such integrated approach might yield synergies leading to improved levels of performance.

2.5.1 Roles of MRP and TOC

Umble et al. (2001) describe ERP systems as powerful tools that offer means to cope with the limitations that constrain the production process. They are designed around a central database that integrates all functions and information as customer orders, production order states, inventory and the like. Especially the real-time information is useful for high quality decision-making. However, ERP systems are not able to diminish the negative effect from management that is focussed on local optima and efficiencies, which is often embedded into long-standing company cultures and procedures (Umble et al., 2001). Moreover, they state that these unfortunate practices are often embedded into ERP systems implemented. The focussing effect of TOC can help managers to identify these negative practices in order to eliminate them. At this point, TOC principles and techniques are helpful for identifying the constraint and for establishing a DBR-style production control system. This emphasise on control is further supported by the visualisation of the current state of the production in form of buffer states. Umble et al. (2001) see the role of the ERP system as the framework and information storage that is the basis for effective TOC usage and replaces classic MRP-style production planning and control. This is in line with findings from Reimer (1991) and Spencer (1991) who have identified the beneficial character of a system that treats MRP or ERP as information systems and TOC concepts (i.e. DBR and buffer management) as the scheduling and shop floor control system. More evidence for these findings comes from

Duclos and Spencer (1995) who have tested MRP and TOC for their ability to avoid stock-outs and to improve overall performance. MRP required the production to produce a static quantity of finished goods every week including the release of all required raw material and components at the very beginning. TOC scheduled the production according to the constraint's need while considering buffer states and fluctuations in customer demand. The simulation using the MRP approach suggested increasing capacity as the best way to reduce stock-outs while the TOC simulation suggested adjustments of the constraint buffer. Finally, Steele et al. (2005) came to a similar result that identifies a composite system of ERP embracing TOC as superior over sole applications of each component. Taylor (2002) describes this combination by stressing the complementary character of the philosophies. He sees MRP as an excellent planning tool that is not strong in execution due to its weaknesses of assuming infinite capacity and neglecting WIP management. TOC takes care of these weaknesses by taking over the role of the master scheduling system. Its DBR technique schedules the production and subordinates all activities under the constraint (e.g. material release, non-constraint usage and output).

To be better able to understand the complementary character of TOC for ERP implementations, Table 4 overleaf lists the main performance issues or weaknesses of the MRP module and provides TOC ideas in order to diminish their negative effects.

MRP issues	Developments	Literature
Forecast and MPS	• TOC solution for MTO and MTA • Dynamic buffer management	• Cohen (2010) • Schragenheim and Dettmer (2001) • Ptak and Smith (2008)
Full BOM runs	• Introduction of buffer management for critical (MTO) or all parts (MTA) • Decoupling of demand for parts and components from demand for finished goods	• Cohen (2010) • Srikanth (2010) • Ptak and Smith (2008)
Manufacturing order release	• TOC solution for MTO and MTA • Actively Synchronized Replenishment (ASR)	• Cohen (2010) • Schragenheim and Dettmer (2001) • Ptak and Smith (2008)
Limited early-warning functionality	• TOC solution for MTO and MTA • Dynamic buffer management • Colour coding of buffers	• Schragenheim and Dettmer (2001) • Ptak and Smith (2008)
Lead-time ambiguity	• TOC solution for MTO and MTA • Actively Synchronized Replenishment (ASR)	• Cohen (2010) • Schragenheim and Dettmer (2001) • Ptak and Smith (2008)
Unresponsive demand determination	• TOC solution for MTO and MTA • Dynamic buffer management • Adjusting buffer sizes according to real demand	• Cohen (2010) • Schragenheim and Dettmer (2001) • Srikanth (2010) • Ptak and Smith (2008)
Lacking priority consideration	• TOC solution for MTO and MTA (priority results from buffer status) • Actively Synchronized Replenishment (ASR) (priority attached to all production orders based on QLT (MTO) or CLT (MTA))	• Schragenheim and Dettmer (2001) • Srikanth (2010) • Ptak and Smith (2008)

Table 4 – MRP issues and TOC solutions

The analysis shows that there is no such thing as a better system or philosophy (Gupta and Snyder, 2009). They continue to state that TOC has its benefits in its robust shop floor control system, which can be integrated into existing MRP implementations. This is in line with Steele et al. (2005) who believe that a unique system could be designed that combines the best features of both underlying systems. Furthermore, the last table shows that TOC concepts are available to address MRP weaknesses. The next section selects an integrative model and describes its components.

2.5.2 An integrative model

This section is intended to describe the latest model for improving production planning and control that is strongly influenced by ideas from TOC such as strategic buffering, replenishment and buffer management (Smith and Ptak, 2010). It has been introduced by Ptak and Smith (2008) and has been refined and put into the context of TOC in Smith and Ptak (2010). Up to this time it has been called Actively Synchronized Replenishment (ASR). The breakthrough success of the concept happened after the public release of Ptak and Smith (2011) due to the inclusion of their concept into the knowledge base of MRP. Starting from this time the concept is called demand-driven MRP (DDMRP). It will be described by establishing the required context first. After that, its concepts and techniques are described to allow for an adequate level of understanding. This is enriched by diagrams and tables in preparation for later simulation activities.

Foundations

Earlier parts of this chapter have already identified major problems of fit of the original "Push and Promote" concept of standard MRP in a world characterised by increased levels of volatility of demand and customers requiring shorter response times to their needs. This justifies a shift away from the central role of inventory towards the recognition of demand as the central driver for decision-making. Firms have responded to this by investing in pull-based concepts as lean or DBR and disabling the MRP push-style components (Ptak and Smith, 2011). Furthermore, a tendency to invest in highly sophisticated forecasting and planning technologies has also been observable, but has not delivered the anticipated results due to the lacking consideration of variability within their concepts (Goldratt et al., 2000). The dilemma many companies are facing is shown in the next Figure 9 that is influenced by Smith and Ptak (2010) and Ptak and Smith (2011).

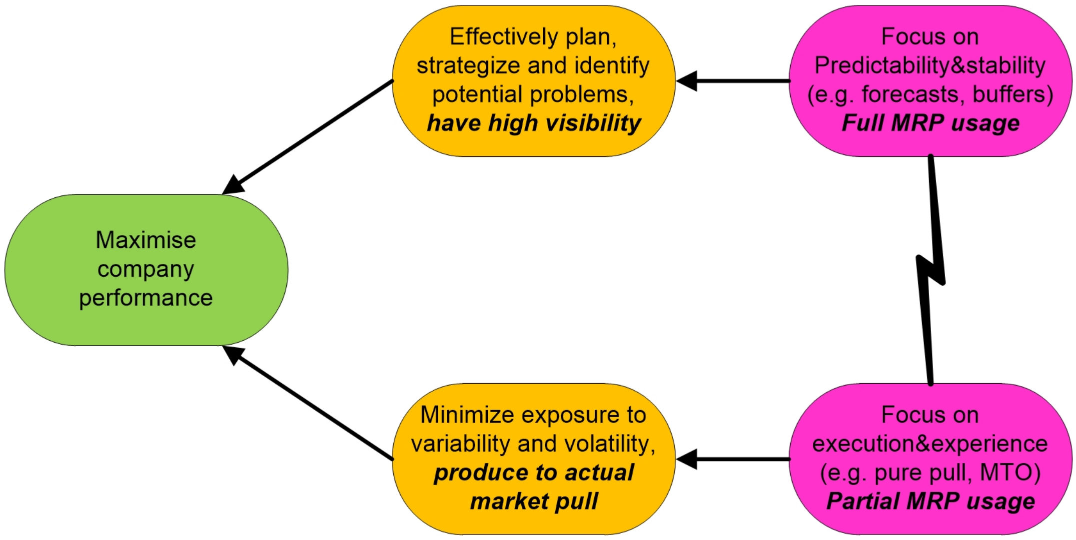

Figure 9 – The MRP conflict today

The conflict and the resulting compromises need to be viewed from two different sides. Ptak and Smith (2011) state that from a manufacturing perspective, companies need to be able to respond and produce to actual demand while carefully considering the availability of material and capacity. However, the already identified shorter time horizons have changed the circumstances in a way that standard MRP tools are not able to cope with. This is the point where the already discussed individual compromises and workarounds come into play. Moreover, the lacking feature or material synchronisation also limits the ability of pull-based tools to unfold their full level of performance (Ptak and Smith, 2011). The other perspective of planning and purchasing requires visibility and stability of plans to ensure material availability, which MRP under the changed circumstances cannot deliver.

The DDMRP approach tries to break the cloud by embracing the beneficial functionality MRP can still or even better deliver (e.g. BOM visibility, capability of netting demand and the connection between purchasing or manufacturing orders to actual demand) while replacing its push-based logic with concepts that consider the need to focus on demand in replenishment and to establish a pull-based logic. It does so by building on the long-term established and recognised functionality of MRP and integrating recent elements of TOC and lean (Smith and Ptak, 2010). By this, it incorporates the three main objectives of the production function of planning, execution and control in a way that becomes visible in the following paragraphs.

Five components of DDMRP

Ptak and Smith (2011) have defined five major components as the building blocks of DDMRP that are designed to circumvent the shortcomings of classic MRP in order to improve firm performance. They are designed to be introduced and applied jointly as “ignoring any of these components will reduce the value of the solution dramatically in most environments” (Ptak and Smith, 2011). The components are strategic inventory positioning, buffer profiles and level determination, dynamic buffers, demand-driven planning and highly visible and collaborative execution. The following Figure 10 helps to understand their interplay and is taken from Ptak and Smith (2011).

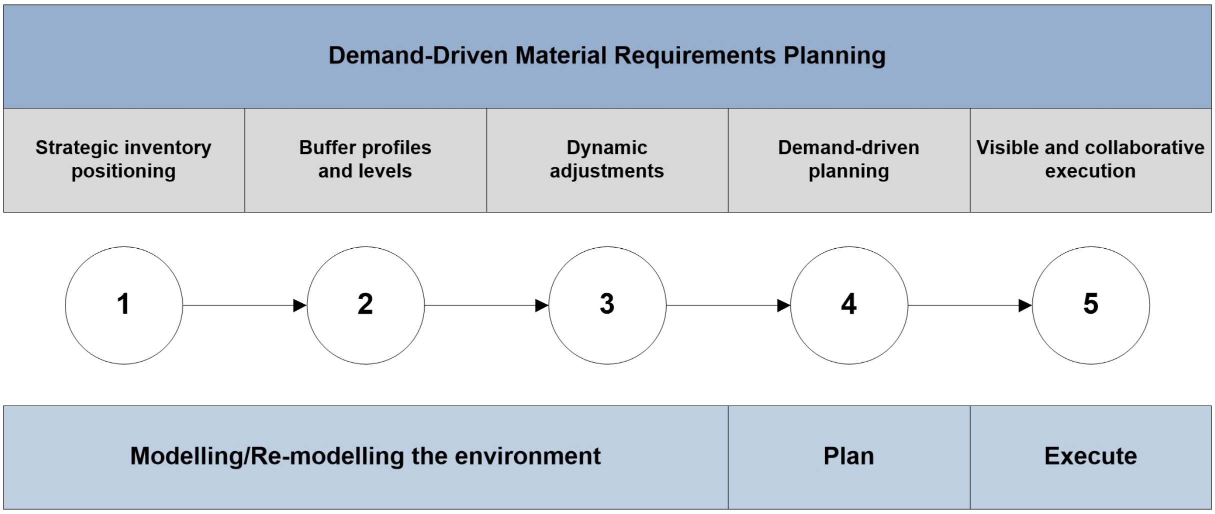

Figure 10 – Five components of DDMRP (source: Ptak and Smith, 2011)

The above figure shows the integrating character of the concept by incorporating the three components of production from planning over execution until control. Each component is described and analysed in turn.

Strategic inventory positioning. Ptak and Smith (2008) begin their description of this component by saying that the question of how much inventory one should hold is irrelevant. In favour of the latter, they suggest asking the question where inventory should be positioned. The main reason for this lies in the protecting nature of inventory. Holding inventory of all parts and finished goods represents a maximum protection against variability but might also be a dramatic waste of resources. On contrary, eliminating inventory everywhere puts the company at risk of destabilising the whole supply chain. The answer to this dilemma is a compromise in form of strategic positioning of inventory.

Smith and Ptak (2010) list five factors they suggest being considered during related decision-making. First, the time a customer is willing to wait and/or the potential for increased sales as an effect of lead-time reductions is considered as customer tolerance time. The main reason is to maintain responsiveness and high levels of DDP. Second, one should protect the supply chain from swings and spikes in demand that could have the potential to cause material requirements the system is not capable of due to limited capacity, material availability or cash. Third, a certain degree of raw materials, parts or components need to be purchased from external suppliers. Since not all suppliers are able to provide an agreed level of service, a variable rate of supply is the result. Inventory is able to protect the supply chain from the resulting negative effects. Fourth, the inventory flexibility in relation to the product structure needs to be investigated. The main tool to be used is an aggregated BOM structure or a matrix BOM that simplifies the recognition of interrelationships. Shared but not stored items are identified and analysed if a decoupling in form of creating inventory might be helpful for increasing stability, compressing cumulative lead-times and simplifying planning by the insertion of buffers. Finally, the protection of key operational areas from cascading disruptions resulting from a dependent sequence of events (bullwhip effect) is sought. It is particularly important in scenarios with complex BOM and long routing structures. Measures include the creation of new material codes and inserting new BOM levels in order to decouple such structures.

Buffer profiles and level determination. Having now identified the positions where inventory should be located, the amount of stock in form of buffer sizes need to be calculated. The overall aim is to define buffers that are sized to represent an asset to the form represented by their protecting characteristics. Thus, the limits are zero on one side and an upper limit that is justified by the item type, its variability, the individual lead-time and likely minimum order quantity (MOQ) characteristics on the other side. Ptak and Smith (2011) suggest three different item types being manufactured (M), purchased (P) and distributed (D) items. The reason for this separation comes from a combination of differences of departmental responsibility, varying levels of control for internal and external replenishment and different meanings of lead-times for these items (i.e. meaning of short, medium or long for internal and external sourcing).

The next influencing factor is variability, which is suggested to be classified into high, medium or low. Variability can have different meanings for internal sourcing or manufacturing (i.e. different amount of demand spikes) and for external sourcing or purchasing (i.e. different occurrences of supply disruptions). Distributed items are subject to variability resulting from both previously mentioned types depending on their position within the internal supply chain.

Lead-time is the third factor determining the buffer profile. Ptak and Smith (2011) again favour a simplistic approach of defining only the three categories of short, medium and long, which are relative to the individual meaning of such categories to a specific company. The specific calculation of lead-times and their categorisation becomes visible in the simulation part of chapter 5 and in the appendix of this document.

Finally, a significant MOQ being characterised by minimum or maximum quantities or only multiples that can be ordered can be of influence for selecting an adequate buffer profile. Again, chapter 5 is intended to provide more details on the basis of real examples.

The resulting 54 buffer types are shown in the next Table 5 overleaf. Ptak and Smith (2011) treat this as a valid proposal since many companies might only use a fraction of them depending on the individual configuration. However, they mention that there might be situations that demand for even more buffer profiles to better reflect the complexity of the companies production function. However, the main point for introducing buffer profiles is to allow for easy management of buffers and to avoid having to treat each part or component individually. Anyhow, the table is at least a starting point from which potential additions or modifications can be developed.

		Make = M	Buy = B	Distributed = D		
Variability categories	Low = 1	M10	B10	D10	Short = 0	Lead-time categories
		M11	B11	D11	Medium = 1	
		M12	B12	D12	Long = 2	
	Medium = 2	M20	B20	D20	Short = 0	
		M21	B21	D21	Medium = 1	
		M22	B22	D22	Long = 2	
	High = 3	M30	B30	D30	Short = 0	
		M31	B31	D31	Medium = 1	
		M32	B32	D32	Long = 2	
MOQ application		M10MOQ	B10MOQ	D10MOQ	MOQ application	
		M11MOQ	B11MOQ	D11MOQ		
		M12MOQ	B12MOQ	D12MOQ		
		M20MOQ	B20MOQ	D20MOQ		
		M21MOQ	B21MOQ	D21MOQ		
		M22MOQ	B22MOQ	D22MOQ		
		M30MOQ	B30MOQ	D30MOQ		
		M31MOQ	B31MOQ	D31MOQ		
		M32MOQ	B32MOQ	D32MOQ		

Table 5 – Buffer profile combinations (source: Ptak and Smith, 2011)

Ptak and Smith (2011) define three distinct buffer zones of the intuitively understandable colours of green, yellow and red as the calculable and manageable buffer zones. Green stands for nothing to do, yellow indicates the rebuild or replenishment zone and red means special attention required. This is in line with the definitions used in the MTO and MTA concepts developed by Schragenheim and Dettmer (2001), Schragenheim et al. (2009) and Cohen (2010) respectively. They add to additional zones that are outside of the calculation in order to complete the picture. Here, dark red means out of stock and light blue indicates too much stock. Cohen (2010) has also introduced such additional zones for completeness. The following Figure 11 shows buffer zones with their meaning.

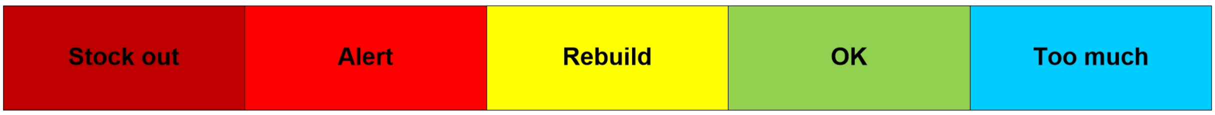

Figure 11 – DDMRP buffer zones

The buffer status in form of the colour coding indicates if additional supply is needed based on the stock available that tis calculated:

$$stock\ level = on\ hand\ stock + open\ supplies - demand$$

The actual calculation of the buffer levels is done by considering different individual part traits. The following Table 6 influenced by Ptak and Smith (2011) shows the information required for performing a calculation.

Group trait inputs	Individual part inputs
• Lead-time category • Make, buy or distributed • Variability category • Significant MOQ factor	• Average daily usage (ADU) • Discrete lead-time • Ordering policy • Location (distributed parts)

Table 6 – Buffer level determination

Each zone of the buffer is calculated by using a function of average daily usage in units and a percentage of lead-time and variability. Recommendations by Ptak and Smith are shown in Appendix 9. The green zone has an option to be expressed in MOQ if this feature is significant. The yellow zone is most often expressed as the ADU over lead-time. ADU can be easily determined for existing products by consulting their historic consumptions while for new products only sales forecasts can deliver the figure. The red zone is divided into two parts being red zone base and red zone safety. Often the red zone base is set equal to the green zone while red zone safety is calculated by using a percentage representing the variability category of the part. Appendix 9 shows the recommended impact rates. The following formula shows the calculation of the buffer level:

$$Buffer\ level = red\ zone\ base + red\ zone\ safety + yellow\ zone + green\ zone$$

The buffer size calculations seem to be more sophisticated compared to the techniques suggested in the context of MTO or MTA environments. Schragenheim et al. (2009) have proposed using ADU plus a certain amount of safety (e.g. 30%) as a starting point in MTA implementations. Independently of a thorough scientific examination of the different approaches, the buffer calculations represent only a starting point. The method of continuously adjusting them to the actual needs of the firm and the fluctuating demand and supply levels is shown in the discussion of the next topic of dynamic buffers.

Dynamic buffer adjustments. Over time, the circumstances that were accurate when the initial buffer levels were calculated change. Reasons for this are the opening of new markets, changes in suppliers or capacity setups or declining markets for some products. This dynamic environment requires buffers to adapt to these almost ever-changing parameters to allow for optimal performance. DDMRP considers recalculated adjustments, planned adjustments and manual adjustments within the model.

Recalculation of buffers is intended to happen based on changes of the ADU rate and based on zone occurrences. Although Ptak and Smith (2011) favour the first, both are described here. Monitoring the ADU in recurring intervals (e.g. quarterly or annually) is useful for reflecting changes in demand into the system. Any significant changes are then used to recalculate the buffer level based on the new valid ADU. It is important to find a suitable time interval to avoid being over or under reactive in order to avoid a systemic nervousness. Another way to trigger recalculations is monitoring of buffer occurrences. Here, a certain number of red zone occurrences could mean that the buffer is set to small while many green zone occurrences may be an indicator for reducing the buffer size. Compared to the ADU-based recalculations, this method involves some difficulties. Thus, one needs to record the occurrences, define an appropriate time interval and has to find an appropriate buffer adjustment size.

Planned adjustments to buffers are an instrument for adapting inventories to changes in demand that are known well in advance (e.g. seasonality, introduction of new products are agreed or discontinuation of products) (Ptak and Smith, 2011b). Seasonality often represents a demand for products that is close to or even above the capacity of a plant. Timely buffer increases create stock that can be used during peak demand times (Smith and Smith, 2014). In case of new products, buffers are often set in line with marketing or sales forecasts. Close cooperation between production planning and sales is strongly advised since any form of promotional activity or unanticipated success of such products might lead to demand level higher then reflected in the buffer size (Ptak and Smith, 2008). Once products reach their maturity and a decision is made to discontinue their supply, timely reductions of the buffer size help to avoid producing unnecessary stock that might need to be wasted once the product is not sold anymore or has to be sold heavily discounted (Ptak and Smith, 2011b).

All plans might get wrong sometime due to many reasons including unanticipated demand peaks the recalculation procedure has not yet reacted to or sales activities that are not known to planning personnel. Both events can be easily identified by introducing an ADU alert. This is a special form of report that monitors the development of the ADU in relation to its anticipated variability. Once a certain threshold is reached, the alert is raised to ensure awareness and proper treatment. Reactions to this alert include close monitoring of the current ADU and its development in the near future and information generation within the organisation about the issue. All this is helpful for making decisions that may leave the buffer as it is for marginal fluctuations or adjustments of the buffer for larger effects.

Demand-driven planning. The main reason for establishing a different way of planning in DDMRP is to overcome the disadvantages from the many rescheduling messages resulting from standard MRP systems that make it often impossible to consider all of them. The DDMRP solution is the separation of parts into five distinct categories or designations as coined by Ptak and Smith (2011). The first category is for replenished parts, which are managed by a colour-coded system in form of a buffer as already described earlier. The buffers are designed as dynamic and are subject to recalculation and adjustments as already explained. Figure 8 shows a typical graphic depiction of such a buffer. A special form of replenished parts is represented by the second category in form of replenished override. These parts follow the same colour-coded buffer logic but are not subject of dynamic adjustments. The reasons for this limitation are mainly derived from warehouse restrictions that do not allow growing a buffer in relation to likely increased demand due to limited space available. The depiction in Figure 12 is valid in a same way as for replenished items with the exception that buffer size and zone levels are static.

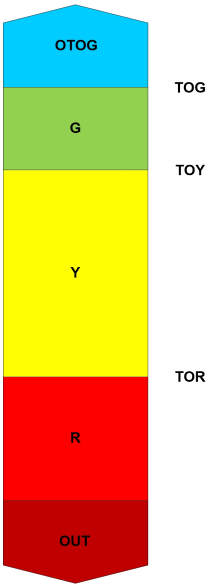

Figure 12 – Buffer for replenished and replenished override parts

The next category is for so-called min-max parts that are familiar from their identical counterparts within MRP systems. They are managed by the two parameters of minimum and maximum stock level, that are subject to recalculation and adjustment in a same way as introduced for replenished parts based on the ADU. The min-max tactics involve monitoring the decrease of stock until the minimum level is reached. This represents the reorder point from which the stock is filled up to the maximum level. Due to the limited monitoring capabilities of this logic, it is only useful for less strategic or readily available parts (Ptak and Smith, 2011). Figure 13 shows an example of a buffer for this category.

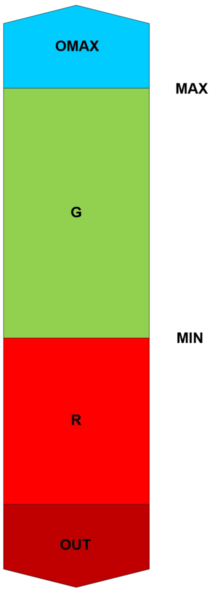

Figure 13 – Buffer for min-max parts

The fourth category consists of non-buffered parts that are not stocked. They need to be purchased or produced according to actual demand. According to Ptak and Smith (2011), it is common for the majority of companies that most of the parts fall into this category. Finally, there is the fifth category of lead-time managed parts. These are non-buffered parts that need special attention due to known issues including limited availability or long lead-times. In order to establish proper management of these parts, the colour-coding scheme is used to create visibility and to trigger appropriate action depending on the state of the part. Figure 14 shows an example.

Figure 14 – Buffer for lead-time managed parts

Having now described the five part categories relevant to demand-driven planning, the next Figure 15 provides an overview on the basis of a tree taken from Ptak and Smith (2011). This is intended to make classification of parts easier in later parts of this document.

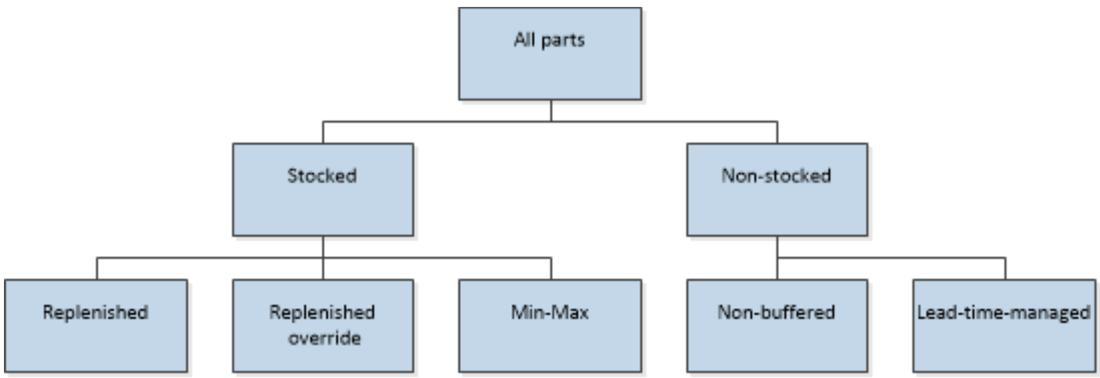

Figure 15 – DDMRP parts classification

Based on the part classification, the DDMRP planning process is designed as a repeated process that calculates actual buffer states based on DDMRP logic for replenished and replenished override parts and for min-max and non-stocked parts following the standard MRP logic. For the last category of lead-time managed parts a proper visualisation and alerting mechanism is maintained to ensure proper awareness. To be able to determine part requirements resulting from different levels of the BOM, the explosion method is still relevant and necessary as in standard MRP. However, the planning is decoupled at any buffered component or part that is designed to be held in form of stock. The BOM of these parts is only exploded once they have reached a buffer state that demands for their replenishment. Based on the daily or even real-time monitoring and visualisation, replenishment decisions are made on the basis of actual demand depicted in the relevant buffer states.

Highly visible and collaborative execution. The previous sections have mainly dealt with the planning part of the production function while this section changes the perspective towards execution. Standard MRP systems are suffering from their limited due date based functionality for establishing priorities in cases of conflicts between customer order requirements and material availability or between production order dates and stock orders. The common workaround in the MRP world is to create subsystems that provide adequate decision-making support at the price of significant efforts. The DDMRP answer to this is a sophisticated alerting system that circumvents the priority-by-due-date issue by establishing alerts based on buffer states while still considering due dates as a second source of information. The following Figure 16 shows the alert categories, which are described in turn.

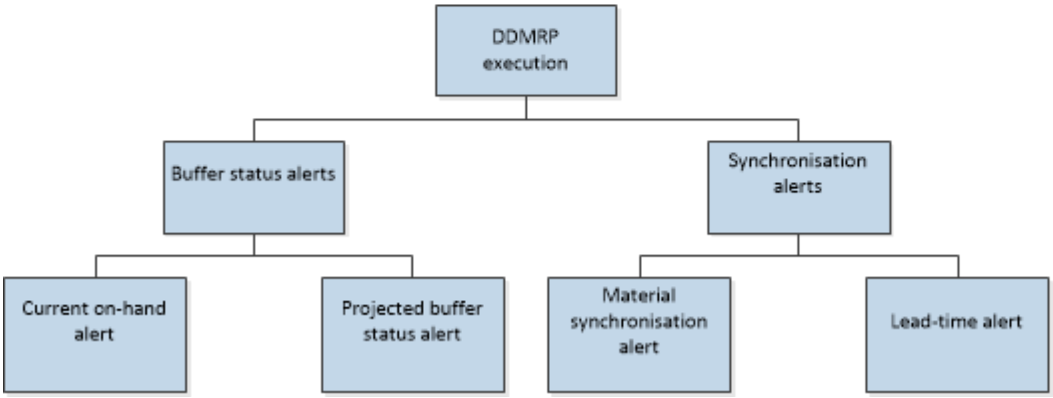

Figure 16 – DDMRP execution alerts

Buffer status alerts are set in relation to a specific buffer state of the total red zone. Ptak and Smith (2011) suggest 50% as a common value to start with. Current on-hand alerts are intended to show to planning and manufacturing personnel what replenished parts are in trouble based on the on-hand perspective. This means that means for planning to see which open supply orders may need to be expedited and for manufacturing which manufacturing order need to be fulfilled first. While this first category of alerts places on-hand stock at the central position of attention, projected buffer status alerts consider the near future (i.e. ASRLT) of parts in form of projected ADU, actual demand (i.e. customer orders) and open supplies. In other words, they try to forecast potential on-hand alerts of the near future. Ptak and Smith (2011) call this a radar screen useful for planning personnel to sort out likely shortages in advance of their occurrence.

The second group of alerts concentrates on non-buffered parts while providing visibility of potential shortages before they happen. Material synchronisation alerts show the earliest occurrence of a negative on-hand stock balance within the ASRLT. This happens when an open supply order is expected to be delivered after the parts are needed. Common reasons for such issues include unexpected high levels of demand, suppliers pushing their promised date later in time or customers requiring a delivery date sooner than initially requested. Raising such an alert is far from providing a guarantee that the issue can be removed. However, the created focus together with defined procedures for dealing with such alerts might have the potential to reduce the negative effect from shortages to an extent. The last category of alerts has already been discussed in the previous section. Lead-time managed parts are monitored and alerts are raised during the last fraction (e.g. last third) of their lead-time in order to create awareness and to trigger adequate actions.

Finally, the collaboration part of this DDMRP component should be focussed. Previous sections have already identified different departments or functions that are involved into manufacturing execution (e.g. planning, manufacturing, sales, procurement). Since communication is often limited, the visualisation of buffer states and the establishment of proper alerts help to tie the organisation together. While providing adequate focus, problem solving is facilitated and simple neglecting is reduced or can be even avoided.

Since DDMRP is suggested to improve the performance of manufacturing organisations by providing answers to unfortunate MRP results, its performance needs to be measured. Furthermore, measurement is not only useful for showing the effects after an DDMRP implementation in comparison to previous achievements, but also for showing the performance development of a DDMRP system over time. Ptak and Smith (2011) are weak on this subject but propose some measures:

- Measure too much safety (OTG Dollars)
- Measure stock-outs for purchased parts
- Measure execution alerts
- Measure resulting DDP

Some of the measures are intended to be used in later parts of this document.

2.5.3 Evaluation

To be able to evaluate a concept, one needs material to be used from practice as well as from academic sources. Ptak and Smith (2011) are clear about the fact that DDMRP has received no significant attention from the academic world until the release of their book. This is in line with findings by the author since a thorough search activity has not yielded any article or book with exception of the three contributed by the inventors. However, since DDMRP has not been developed in isolation of other ideas and concepts (e.g. TOC and lean manufacturing), an attempt is made to show relationships to better-evaluated roots of DDMRP components. The following Table 7 shows the results.

DDMRP parts	Defined by DDMRP	Explained by TOC	Explained by Lean	Other methods e.g. Six Sigma, …
Strategic inventory positioning	• Sophisticated new concept • Detailed guidance	• Some advice on positioning of inventory • VATI analysis	• Pure Lean means zero inventory • Lean replenishment	• Waste elimination and time compression
	• Ptak and Smith (2008) • Ptak and Smith (2011)	• Spencer and Cox (1995) • Goldratt et al. (2009)	• Naylor et al. (1999) • Bowersox et al. (1999)	• Beesley (2007)
Buffer profiles and level determination	• Detailed calculation rules • Ready to apply concept	• MTO and MTA introduce buffers in a similar way derived from TOC buffer management	• Application of buffers in lean context	• Buffers sized responding to needs in TQM • Reasonably sized buffers in Six Sigma
	• Ptak and Smith (2011)	• Schragenheim et al. (2009) • Cohen (2010)	• Choo and Tommelein (1999)	• Svensson and Wood (2005) • Han et al. (2008)

Dynamic buffers	• Concept is similar to TOC but more sophisticated • Clear rules	• MTO and MTA recognise adjustments • Size is more based on intuition and experience	• Buffer determination and adjustments in Lean	• Buffer adjustments in TQM
	• Ptak and Smith (2011)	• Schragenheim et al. (2009) • Cohen (2010)	• Enginarlar et al. (2005)	• Miller (1998)
Demand-driven planning	• Demand at the centre of decision-making • Categorisation and incorporation of MRP logic is new	• MTO and MTA place demand at the centre of decision-making	• Pull logic at centre of Lean	• TQM mainly focuses on internal processes • Not explicitly part of Six Sigma
	• Ptak and Smith (2008) • Ptak and Smith (2011)	• Schragenheim et al. (2009) • Cohen (2010) • O'Leary (2000)	• Naylor et al. (1999) • Womack and Jones (2003)	• Harari (1993) • Andersson et al. (2006)
Highly visible and collaborative execution	• DDMRP defines rules and puts them into relation with existing MRP logics	• MTO and MTA include some advice but are rather weak • Colour coding introduced	• Collaboration in many forms embedded • Visible execution following rules	• TQM and Six Sigma set main focus on improving quality and waste reduction
	• Ptak and Smith (2011)	• Schragenheim et al. (2009) • Cohen (2010) • O'Leary (2000)	• Adamides et al. (2008) • Pool et al. (2011)	• Mehrjerdi (2009)

Performance measurement	• DDMRP is rather weak on this subject but makes suggestions similar to common standards and concepts of its own logic	• TOC performance measurement and throughput accounting is a thoroughly described concept	• Lean uses well established operational measurement	• TQM introduced customer-centric measures • TQM delivers sophisticated performance measurement • Six Sigma measurement focuses mainly on quality
	• Ptak and Smith (2011)	• Goldratt (1990) • Cox et al. (1998) • Boyd and Cox (2002)	• Shah and Ward (2003) • Bhasin (2008)	• Neely et al. (1995) • Motwani (1998) • Antony and Banuelas (2002)

Table 7 – Roots of DDMRP

The table showed the connections of DDMRP to the areas of MRP and TOC that have been described and evaluated in previous subchapters. Mentioning only TOC and MRP as the main roots of DDMRP might be an over simplistic view since elements from many methodologies such as lean manufacturing are also embedded into the concept. However, since the development of TOC itself has also not happened in a vacuum, this view is seen to be sufficiently correct. The concept seems to be a way of answering MRP weaknesses by drawing from TOC and other sources that have been proven to be successful in manufacturing applications. The question of what these other sources might be is not difficult to be answered. TOC has surely not been developed in isolation of other ideas and improvement methodologies such as lean manufacturing or six sigma and many more (Berry and Smith, 2005). However, the influence of TOC in form of wording and concepts is so obvious that it is seen as one main root of DDMRP acknowledging some form of simplification.

Ptak and Smith (2011) provide some examples of early adopters of DDMRP in form of two manufacturing companies being involved into food freeze drying and mining equipment. Both companies report DDP improvements, lead-time compression and inventory reductions. Demand Driven Technologies (2014) mention two more companies producing packaging solutions and wooden equipment that report similar results. Although one needs to be cautious about reports originating from the direct surroundings of the inventors of DDMRP, in absence of more thorough investigations they could be seen as indicators that need to be empirically verified.

While considering the relevance of DDMRP to the practice setting of manufacturing companies, the availability of software is a major issue. It has been identified that MRP technology is embodied into all major ERP systems on the market. However, at the time of writing only one ERP system designed for medium and small organisations (Aquilon, 2014) and one add-on software (Demand Driven Technologies, 2014a) was available that supported DDMRP. However, the fact that DDMRP has been included into the third edition of a standard reference book on the subject of MRP could be seen as an accelerating factor for its introduction into other more prominent ERP systems. Early indicators for this can be found among Scavo (2011) who states that SAP is working on its MRP module to integrate DDMRP logic and Microsoft (2012) saying that their Axapta or Dynamics AX product is able to support MRP, MRP II and DDMRP ways of working. The author is not going to put unjustifiable high weight on these pieces of evidence. Nevertheless, the concept is getting more and more prominence.

It can be concluded that DDMRP is well placed on the shoulders of its giant predecessors and addresses major weaknesses of MRP by providing promising answers inspired by methodologies like TOC. While borrowing from evaluations of its predecessors, it could be justified as an interesting and sophisticated new concept for the production function of manufacturing companies. A simulation to be shown later in this document is intended to provide more information useful for assessing its performance improvement potential.

2.6 Conclusions

MRP functionality dealing with material requirements planning has been developed and further improved from the 1970s until today while maintaining the basic replenishment concept of “push and promote”. The resulting misfit with today’s global market requirements is often addressed by introducing manual workarounds or by investing in highly sophisticated forecasting technology, which most often is not delivering the expected results.

TOC has been introduced almost 25 years ago as a management and improvement philosophy that embodies the main paradigms of logistics, global performance measurement and thinking processes. Quite significant amounts of academic articles and books as well as case studies covering practice implementations have helped to further develop and refine it as well as to show its beneficial potential to manufacturing companies.

DDMRP is a quite new concept that builds on a thorough understanding of the shortcomings of MRP systems. It provides solutions to such issues by drawing from popular improvement methodologies as TOC. By this, it incorporates the strength of MRP technology where appropriate. Furthermore, it provides more detailed concepts and tactics in comparison to its TOC relatives in order to ensure proper applicability to practice.

The literature review has prepared the ground for the later case study by identifying common practices used in manufacturing companies and resulting issues. Especially the first part dealing with standard MRP and ERP systems seems to be helpful for answering the first research question of **what the issues are in InkCo's current planning and control system that limit performance**. (RQ1)

The rest of the chapter has reviewed main elements of the TOC methodology and the recent concept of DDMRP, which has been identified as an attempt to address MRP weaknesses by using TOC concepts to form a coherent system for production planning and control (see Chapter 2.5.2 and 2.5.3). Based on these findings, the literature review has not only been able to address the first research question dealing with limited performance but also to develop concepts that might be able to address these issues and by this improve the overall performance of the production function. Therefore, it tried to determine **to what extent the features of MRP/ TOC/ DDMRP address these limitations**. (RQ2)

A later part of this document is intended to show the full breadth of the DDMRP concept by undertaking a simulation exercise on the basis of real data from a manufacturing company.

3 Research methods

3.1 Introduction

The purpose of this chapter is to outline the research methods to be applied in a conceptual and theoretical way. It first revisits the two research questions and breaks them down into smaller pieces of information that needs to be collected. After that, the research design is developed and justified by briefly explaining main epistemological directions first. Following this, a description of the quantitative and qualitative approach of this research is provided in preparation of the presentation of the research design of this document. The next section describes the instruments of this study and focuses on determining the quality of the study to be undertaken by focussing on the criteria of validity and reliability, which is rounded up by a short paragraph identifying likely researcher bias. The chapter continues with the description of data sources and the relevant collection procedures to be used during the research process. Following this, the analysis of the data to be completed is outlined. It is subdivided into the three logical steps of understanding the current system, interacting with existing theories and development of a new model. Finally, an attempt to match the research purpose with methods to be applied draws from the previous descriptions and justifies the selections and decisions made. Following this, the activities that have happened in order to address the data needs of this study are presented including information about tools and participants. Final conclusions shall summarise the findings made.

3.2 Restatement of the problem

The goal of this study is to develop an effective system of production planning and control for the organization in focus to be implemented together with a new ERP system. This is planned to be accomplished by developing answers to the research questions already shown in the introductory chapter, which are now broken down into sub-questions facilitating the formulation of the related answer later. The sub-questions are informed by findings made in the previous chapter as well as by personal experience of the author, obtained by some preliminary case study research activities.

RQ1 What are the issues in InkCo's current planning and control system that limit performance?

a) What are the most undesirable effects of the current system?
b) What departments and functions are involved into forecasting?
   i. How and why is forecasting done in the way it is?
   ii. What is the goal of current ways of working related to forecasting?
c) Are there any quality or reliability issues?
d) What departments and functions are involved into demand planning?
   i. How and why is demand planning done in the way it is?
   ii. What is the goal of current ways of working related to demand planning?
e) How is forecasting and demand planning related today?
f) What shape follows the current production layout?
g) How and why is buffer management implemented today?
h) What is the nature of procurement?
   i. Supplier relationship
   ii. Availability issues
   iii. Lead-times
i) What are the expectations of customers?
   i. Customer relationship
   ii. Delivery expectations
   iii. Lead-times

RQ2 To what extent do the features of MRP/ TOC/ DDMRP address these limitations?

a) What is TOC theory and ERP reality suggesting?
b) How can theory and practice be integrated into a coherent model?
c) What are the benefits of this new model?
d) What are the results of such a new system of production planning and control?
e) To what degree are the findings generalizable?

3.3 Research design and procedures

This section should first establish the ground by presenting a brief description of the main philosophical themes relevant to operations research concluding in the research methodology being followed in this concrete piece of research. This is followed by a discussion of the main concepts of qualitative and quantitative research strategies leading to the research approach specific to this paper.

3.3.1 Research methodology

According to many well-known researchers as Guba and Lincoln (1994), Miles and Huberman (1994) or Gill and Johnson (2002) identifying the theoretical paradigm for a specific research is crucially important for establishing a thorough understanding of the findings in their surroundings characterised by basic assumptions and concepts (Bogdan and Biklen, 2003). Furthermore, research tasks in operations management quite often demand for acceptance by practitioners as well as academics while activities might range from solving small problems up to making sound contributions to the existing body of knowledge (Flynn et al., 1990, Filippini, 1997 and Forza, 2002). This involves searching for theoretical constructs that are not only valid in its specific environment but also in a wider setting. This is supported by Drejer et al. (1998), who identify this dilemma as being a specific characteristic of operations management research. Voss et al. (2002) develop this finding further by explicitly defining the object of study as physical and human elements in an organisational setting.

The first part being physical elements broken down into efficiency and effectiveness has been in favour of researchers belonging to the positivism realm. This has been empirically proven in articles by Scudder and Hill (1998), Pannirselvam et al. (1999) and recently by Gupta et al. (2006), who reviewed journal articles published in major journals. The second part of human elements is treated as autonomous objects (Gabriel, 1990) while often ignoring their ability to reflect upon problem situations and act upon this (Robson, 2011). Reality is then formed out of discrete characters that can be clearly recognised and classified (Christie et al., 2000). Quite often the research stays remote from the phenomena under investigation (Anderson, 1986) while using techniques as experiments or surveys that have a specific outcome in focus (Christie et al., 2000).

Other researchers as Meredith et al. (1989), Drejer et al. (1998) and Wacker (1998) have raised an argument supporting early findings by van Maanen (1988) that human being need to be studied while considering their environment and their ability to change due to external influences. This leads to their main argument of the interpretivist realm that understanding of social phenomena requires knowledge about individual development of meaning since it is socially constructed and therefore context-specific. Considering the described needs, methods like in-depth interviews, personal observations or focus groups might be more useful for achieving high quality results.

The previous part has identified the two poles or extremes of the epistemological continuum. Going back to where the discussion started poses the question of the specific needs of operations management research. Positivism favours the problem-solving and user-centric approach while interpretivists emphasize the importance of understanding human and social components of knowledge creation. Perry et al. (1997) fill this gap by suggesting realism as a suitable way for understanding problem situations. According to them, it consists of elements taken from both worlds to allow for attaching specific realities to findings. Exactly this provision of context to specific findings enables researchers to triangulate specific pictures of reality with different perceptions (Bhaskar, 1978 and Perry et al., 1997).

Considering all the presented facts, realism might not deliver the degree of generalizability as positivism does nor does it consider organisational complexity as well as interpretivism tries to. However, as Ihme (2012) concludes a similar discussion, the explicit inclusion of qualitative and quantitative techniques and the relaxed position regarding covering laws allows for consideration of human sense making. This makes it an attractive approach for many research projects supported by Hausman (1992), who stresses context-specific nature of the applicability and usefulness of theories. He concludes his article by pointing out that known applicability or performance in a couple of situations might not prove their general applicability. Concluding this discussion by a quotation from Steenhuis and Bruijn (2006) helps to understand the debate better as they say, that "[…] different approaches should not be seen as more or less valuable but rather as a portfolio of techniques that together can help to create insight into the problems of and solutions for the field of operations management."

Taking the specific needs of this study into account, the selection of the realism paradigm flows almost naturally from the discussion presented in the last paragraph. The main category of this study can be classified as operations management, as it focuses on effective planning and control of resources and activities that are required to provide a market with tangible goods (Waller, 2003). A specific situation in form of current levels of performance needs to be analysed and understood. Further on, a model is developed and tested to verify its potential to improve current results. The first part demands for an ability to ask questions and to interact with people in order to develop the required understanding of reasons for ways of working in place (Wacker, 1998). Betrand and Fransoo (2002) classify the second part where a model is developed, analysed and tested by investigating the relationships between control and performance variables as purely positivist. Since a phenomenon in form of the current situation is not fully understood (Bonoma, 1985) and a model should be developed from existing theory (Bhaskar, 1978), realism seems to be the adequate paradigm to follow throughout this study.

3.3.2 Quantitative research methods

Developments in operations management research from the 1980s until quite recent work can more and more characterised by a switch from qualitative techniques towards empirical research methods (Forza, 2002). The main reason for this has been the wish to close the gap between management theory and practitioners' needs and to increase scientific recognition in the operations management field (Fillipini, 1997 and Scudder and Hill, 1998). Survey research has become one of the most attractive methods over the years due to its ability to serve research needs varying from solving a specific problem up to contributing to the existing body of knowledge (Babbie, 1990 and Forza, 2002).

This is realised by collecting information from individuals about themselves, specific interest areas or the social context to which they belong (Rossi et al., 1983). Information is usually collected only from a subset of the whole population in focus mainly for economic reasons, which is then intended to be generalised to larger parts with an anticipated level of accuracy (Rea and Parker, 1992).

However, data does not need to result from survey analysis but can also be generated by performing experiments and collecting the results in a laboratory or desk environment. According to Robson (2011) there are two main approaches likely to be of real world interest being quasi-experiments and single-case experiments. Although usage of statistical techniques vary according to the chosen approach, both try to determine a degree of fit between variables in terms of one variable influencing the other. Bertrand and Fransoo (2002) put these concepts in the context of real world problem solving by developing theoretical models being derived from the literature in order to improve a specific situation or process. Such models are then tested with experiments or computer simulations to demonstrate validity and improvement capability (Handfield and Melnyk, 1998). Furthermore, simulation has been identified as a viable means of comparison of original data and such being generated artificially. Feng et al.

(2012) identify simulation as a viable way for collecting and analysing data, which is also capable of helping to evaluate the differences between two sets of data. This is perfectly in line with Watson and Polito (2003) who also used simulation in the area of production planning and control.

Kaplan and Duchon (1988) allocate quantitative techniques and views to the positivist perspective by highlighting where hypothesis are mainly tested by using controlled experiments and statistical analysis. They found that a majority of researchers favour such approaches due to their scientific nature or at least their scientific appearance. A main fault of these techniques has been stressed by Kauber (1986) who identified that the requirement for reproducible results demands for neglecting the context. Kaplan and Duchon (1988) summarise the described disadvantage by citing a reviewer: "Stripping of context buys objectivity and testability at the cost of deeper understanding of what actually is occurring".

3.3.3 Qualitative research methods

Derived from the standards of sociological studies, qualitative methods are common also in operations management research (Hirschheim et al., 1986; Robson, 2011). They are often applied when a full understanding of phenomena together with underlying reasons, opinions and motivations is sought (Golafashani, 2003). Denzin and Lincoln (1994) identify qualitative research as being multi-method in its focus that involves an interpretative approach. They continue to explain that studying phenomena in their natural settings to develop high levels of detail and to understand the meaning people bring to them is at the heart of qualitative studies.

Accordingly, researchers are often involved personally by visiting the location of the phenomena to be researched (Bashir et al., 2008). This involves collecting a series of empirical material like interview transcripts, notes from personal observations or case studies. Robson (2011) supports this by identifying words as the most common form of qualitative data collected and improved by techniques mentioned previously.

Yin (2009) characterizes qualitative studies by the detailed involvement of the researcher in natural settings and by avoiding prior commitment to theoretical constructs or hypothesis before gathering any data. This first highlights the attempt to produce rich accounts of reality and specific meaning to phenomena and the second the explorative feature of qualitative studies. Kaplan and Duchon (1988) use these findings to characterize these methods as being interpretative in nature. However, they also stress one main disadvantage of such methods being the lacking ability to explain variance of processes. Nevertheless, qualitative studies can act as a trigger towards the development of explanations about how and why processes occur by yielding adequate data.

Common methods are described briefly next in preparation of the next section.

Case study research

Case studies research uses single or a limited number of settings in form of cases for analysing subject-based and context related facts (Yin, 2009). According to Eisenhardt (1989), the data collected can be mainly qualitative, qualitative enriched by statistics or a mixture of qualitative and quantitative techniques. She continues her description by identifying that case study research is a valid approach for quite different purposes, such as providing understanding of a situation, testing theories for validity (deductive process) or for developing theory (inductive process). Regarding the validity of the resulting theory, adequate levels of internal validity can be achieved by triangulation (Eisenhardt, 1989). She also discusses the subject of external validity. Although, rich sources of data might provide support for external validity, amounts of data used for analysis often need to be limited by having the intended theory in focus as well as analytical induction. The last element supports reliability due to the iterative nature of case study research. Bloor (1978) describes this by pointing to the setting of tentative hypothesis prior to data collection, which can be refined during the process until no further refinement is needed. Finally, generalizability crucially depends on the quality of hypothesis shaping characterized by adding representative cases and refining emerging theoretical samples towards achieving a good fit.

Single-case studies

Voss et al. (2002) in general and Nock et al. (2007) in detail have examined single-case studies in terms of their usefulness to specific research tasks. While multiple-case studies have a greater potential to deliver results that are generalizable, single-case studies allow the researcher to go into more depth. Yin (2009) gives an example of a single holistic unit (e.g. a state, a company and the like) being analyzed following a time-series design where performance values are analyzed before and after a major change of the system. He further provides rationales for single-case studies to be adequate design choices as shown in the following Table 8.

1.	**When it represents a critical case in testing a well-formulated theory**
2.	**Where the cases represents an extreme or unique case**
3.	**For cases that are representative or typical**
4.	**When a case is the revelatory or previously untouched**
5.	**The longitudinal case; a single-case is studied at two or more different points in time**

Table 8 – Rationales for single-case studies

TOC thinking processes

This methodology has already been discussed in detail in the previous chapter (see Chapter 2.3.4). Their main purpose is trying to find answers to Goldratt's (1984) three generic managerial questions of what to change, what to change to and how to cause the change (Kim et al., 2008). This is done by applying cause-and-effect logic to identify sufficiency and necessary condition logic to validate findings (Mabin, 1999). Scoggin et al. (2003) describe the TOC thinking processes as a managerial approach that helps to understand why desirable or undesirable situations occur, to estimate the impact managerial actions might have on undesirable effects and to provide guidance on how to implement the change. They do so by offering a set of tools and techniques already described in the previous chapter. Scoggin et al (2003) stress further the importance of having achieved a thorough understanding about the background and the details of an existing situation. The resulting undesirable effects (UDEs) act as the main information to be used for identifying the main problem or the root cause. The next step is the creation of the current reality tree (CRT), which describes "the starting point for the existing system state and includes the core problem, the basic conflict or managerial dilemma and all of their respective supporting rationale and assumptions" (Scoggins et al., 2003). The individual entities form the logical foundation for the case in focus in form of the CRT. The next step is to determine how proposed changes might be helpful to turn the UDEs into desirable effects (Dettmer, 2007). This is done by creating the future reality tree (FRT), which "primary purpose is to ascertain logically the effectiveness of new ideas or injections before they are actually implemented" (Scoggin et al., 2003). Although more tools exist, the previous description addresses the need of this specific research task only.

3.3.4 The research approach

The previous sections have described qualitative and quantitative research methods briefly while also identifying some of their weaknesses in the area of lacking context or difficulties to address variance or contingency. Kaplan and Douchan (1988) have already observed a tendency to combine methods in order to address such weaknesses. Van Maanen (1983) stresses that qualitative and quantitative techniques have not to be seen as opposing poles rather than as supplementing in order to increase robustness and to provide a fuller picture. This early idea was further developed and refined by researchers originating from both major directions. Thus Yin (2009) explicitly asks for quantitative data to be used in case studies to enrich the set of data. He also identified in Yin (2006) that there are case studies that are heavily qualitative and others being heavily quantitative depending on the context. Creswell (2009) advocates for qualitative data to be used for finding reasons for phenomena quantitative research has uncovered.

To be able to construct an adequate research design, one first needs to analyse the needs of the study. Wacker (1998) identified two main categories of operations management research being either analytical research or empirical statistical research. In line with him, this study can be classified as an empirical quantitative case study, because it looks only at a single case for developing a new production planning and control strategy. Case studies are defined by Yin (2009) as “an empirical enquiry that investigates a contemporary phenomenon within its real-life context”. Saunders et al. (2007) found that case study strategies are often applied to exploratory and explanatory research. Based on the stated research questions, this study fulfills both types where case studies are appropriate. The second part of this research uses simulation as a means for finding the answer to the question if a specific planning and control methodology justified by the case study and literature reviewed is capable of improving performance. This more exploratory kind of research is intended to produce information with a strong practice focus that is expected to be better accessible and understandable for a mostly non-academic audience present at the case company. The approach is comparable to Watson and Polito (2003) who also used a case study to understand issues and by this to produce information being used to develop a scenario where simulation is used to compare two sets of data being the actual and the one generated by the simulation itself.

According to Yin (2009) case studies are particularly suitable to deal with “how” and “why” questions being exploratory in their nature. He continues to identify control over behavioural events as a method selection criterion. Yin suggests for situation where control is possible to use experimental methods and for others to consider case study research. As the researcher has no control over past decisions in the field of production planning and control, case study research seems to be justified. However, the researcher expects to have some control over future behaviour since it will be influenced by the model to be developed. Since the integration of the new model into daily procedures is beyond the scope of this research, the condition holds anyhow. Yin's (2009) final condition distinguishes study focus on historical events from others concentrating on contemporary events. The first is more suitable for a historical study while the latter indicates the appropriateness of case study research. This research has a medium-sized organisation in its current state in its focus. Numerical data to be used could be judged as historical (i.e. 2012 and 2013), but as the systems and procedures the data results from have not been changed since today, they can be judged as contemporary. Therefore, the third criterion indicates the use of case study research.

Considering criteria determining the appropriateness of case study research for a specific research project, Stake's (1995) criteria are examined now. They are shown in Table 9.

a) Which cases are likely to maximise what is learned?
b) How easy it is to access research informants?
c) Carefully consider the uniqueness and context of alternative selections, for those may aid or restrict our learning.

Table 9 – Selection criteria for case studies

Examining the criterion a), it is the most beneficial way to involve key players in the organisation into interviews to be able to determine the current and maybe yet undocumented ways of working and to uncover reasons for their existence. Considering any previous research might not be helpful as the systems are expected to be specific to the organisation in focus to a certain extent. Addressing criterion b), the role of the researcher within the organisation in focus does not indicate any major obstacles in accessing relevant people from various functions. Finally, this study includes all relevant people from the organisation in focus, which means the full population. Any aid or restrictions to be unveiled context-specific and therefore unique characteristics of the organisation in focus.

The support for case study research to be applied to this study from two different authors' concepts justifies its selection. This requires another decision, namely if multiple or single case study research should be undertaken. Based on the advantages and disadvantages of single-case in comparison with multiple-case studies, the advantage of the former allowing for performing in-depth observation and analysis is expected to outweigh the resulting disadvantages. Especially Voss et al.'s (2002) identification of limited generalizability can be weakened, because wider generalizability is not sought in a company-specific improvement initiative. However, if one relaxes the boundaries of industry and product to a certain degree, generalizability cannot be ruled out.

Finally, the decision to use simulation as an additional method to develop ideas resulting from the case study further and to test them in a real world scenario needs to be justified. It has already been stated previously that proper simulations are based on a thorough understanding of the company and likely issues. Furthermore, the case study is intended to conclude with a promising new way of production planning and control justified by information collected during the related research activities. Therefore, the prerequisites for undertaking simulation exist adequately and the manufacturing context almost demands for simulation as Moon and Phatak (2005), Rossi and Pero (2011) or Smith and Joshi (1995) suggest.

3.4 Instrumentation

This paragraph is designed to explain the instruments used in this research being the aide-mémoires for the semi-structured interviews shown in the appendix of this document (Appendices 1-4), the database of the current ERP system and the questionnaires used to determine the current situation also shown in the appendix of this document (Appendices 5-8). In its second half, an attempt to show the validity and reliability of the research approach is made, concluded by an identification of likely researcher's bias.

To be able to explore the current ways of working, semi-structured interviews are an adequate method to allow for approaching a situation through the participant's own perspective and in the participant's own terms (Denzin, 1989 and Robertson and Boyle, 1984). They enable the interviewer to follow the arguments the interviewee makes, which has the benefit of ensuring flexibility in a subject area where the interviewee possesses more knowledge than the interviewer (Briggs, 2000). The aide-mémoires are designed for the specific situation and audience and contain topics to be covered to encourage a certain degree of consistency. Thus, using semi-structured interviews guided by appropriate aide-mémoires creates a balance between consistency and flexibility (Zhang and Wildemuth, 2006).

The current ERP system runs on an AS/400 machine by IBM using a DB/2 database, which is accessible by using standard SQL queries. The database design roughly follows an entity-relationship type of design that allows for relatively easy access to information needed.

Among such information, product master data, production line and workplace configurations, production layout and the like are planned to be extracted. Furthermore, various quantitative data in form products and its frequency of production and many other production statistics are available. Using this real data for understanding the initial situation as well as for testing the new model with real demand and stock figures makes perfectly sense (Lee et al., 2008).

The questionnaires are used to involve a larger group of colleagues in this study as one reason and for establishing completeness of capturing relevant information. While semi-structured interviews may identify the current ways of working together with issues resulting from those, the question remains open if all relevant topics are covered (Bashir et al., 2008). Therefore, questionnaires developed together with IT colleagues are used to make sure that all relevant questions are asked. It is planned to involve shop floor managers as well as logistic managers on one side and colleagues from the procurement and sales function on the other. Having this full picture in hands, performing a triangulation exercise using the interview data and the questionnaire results has the potential to strengthen the quality of the study. Patton (2001) and Creswell (2009) support this finding as they have identified the potential of triangulation to increase validity resulting from the usage of data from different sources of data to create a coherent picture of the reality observed.

3.4.1 Validity and reliability

The criteria of validity and reliability apply to both quantitative and qualitative modes of study as features to be demonstrated, which show that the study is credible (Boberg, 2006). She continues by citing Patton (2001) who stated that in quantitative research, credibility depends upon the construction of the test instruments while in qualitative research, the researcher is the instrument. Quantitative empirical case study research is designed to develop a model and test the validity of it in terms of its potential to solve the problem (Bertrand and Fransoo, 2002). However, the test for validity and reliability needs to be conducted for both modes of study since they are part of this research task.

Quantitative component

Bashir et al. (2008) identified that quantitative studies use experimental models and quantitative measures to test hypotheses. Furthermore, measurement and analysis of causal relationships are in focus of quantitative studies (McMillan and Schumacher, 2006). This is most often done by using widely standardized mathematical procedures and methods that emphasize on facts and causes in form of numbers, which are analyzed and then presented in statistical terminologies (Golafashani, 2003).

In this context, validity means that one needs to make sure that the means of measurement are accurate and that they are actually measuring what they are intended to measure (Salkind, 1997). The main application of quantitative research techniques is the validation of the model to be designed. The simulation approach uses real data from the current ERP system as the input into the model. The resulting figures are operational measures like stock levels, out-of-stock figures and the like, which truly measure what is important to the organization. The methods of measurement are standard procedures in the field of statistics.

Consistency is ensured by using unique definitions for the variables measured for the initial and the model situation and by using the same operational data as the input to the test. Reliability in quantitative research is defined by Charles (1995) as repeatability. Since the data to be used for the simulation tasks is identical, repeatability is almost obviously given.

Qualitative component

Golafashani (2003) described qualitative studies as an attempt to understand phenomena in its context specific settings, in which the researcher's main focus is to unveil the ultimate truth while avoiding manipulating the phenomenon in any kind. Bashir et al. (2006) stress the importance of getting in touch with participants in their individual settings and environments to achieve a certain level of detail. They continue their description by mentioning the most common methods of data collection being interviews, personal observation and case studies. However, achieving validity and reliability has the same crucial importance here as for quantitative studies although most often described as the personal task of the researcher to show credibility (Lincoln and Guba, 1985).

Following the last claim, Golafashani (2003) stresses that in qualitative research the terms validity and reliability could not be treated as separate features. He suggests using the terminology of credibility, transferability and trustworthiness instead. Seale (1999) supports this reframing of the quality criterion by emphasizing the importance of trustworthiness. Moreover, others like Lincoln and Gupta (1985) or Steinbacka (2001) argue that the quality focus in qualitative studies need to be set on validity since it cannot be assumed without its prerequisite in form of reliability. Therefore, the validity of the study is tried to be shown next.

Many researchers as Scriven (1991) and Patton (2001) identified the importance of triangulation of the findings for improving validity and credibility of qualitative research.

This technique can be described in different ways like Scriven's (1991) approaching a subject from different ways or Patton's (1987) validation attempt of using data from different sources and perspectives. In this study, triangulation of the data is intended to happen by comparing the interview data representing the management's view with the questionnaire data representing the view of people being in daily charge of operations in a more practical way. This should help to ensure consistency of the findings as well as completeness of understanding. Furthermore, personal observation enriched by data derived from the current ERP system acts as a further source for comparing with the findings already established. This might result in further small interviews to clarify any issues. Moreover, standard patterns in form of UDEs, UDE maps available from TOC literature are used to compare the case with more general findings. The resulting degree of fit is expected to improve validity further since uses knowledge that has been used and verified in many cases before.

Stuart et al. (2002) add to the quality discussion by picking up Lincoln and Guba's (1985) and Seale's (1999) emphasis on rigor. They suggest applying Yin's (2009) four test criteria intended to provide guidelines for enhancing validity and reliability in case-based research. The criteria are construct validity, internal validity, external validity and reliability.

Construct validity focuses on the appropriateness of operational measures for the concepts being researched and ensures consistency with the literature dealing with similar situations (Kidder and Judd, 1986 and McCutcheon and Meredith, 1993). Stuart et al. (2002) mention three tactics that help to achieve high results on this criterion. First, the origin of data and the ways of obtaining it should be clearly described. This is done in an open and consistent matter in this chapter. Second, a chain of evidence should be enabled that allows somebody else while using the same data to arrive at comparable results for the various constructs and operational measures of the study. Any form of subjectivity and biased interpretation is reduced by using standard definitions for operations measures and constructs that are derived from the literature and the current ERP system that shapes current ways of working. Third, it might be helpful to have key players in the organization reviewing the draft of the case. This will happen because finalization of the first capturing stage of the current situation is intended as a formal sign off of the report.

Internal validity means that one is able to show that certain conditions lead other conditions in a causal relationship (Cock and Campbell, 1979 and Yin, 2009). According to Stuart et al.

(2002) internal validity can be shown by finding actual data patterns that match proposed patterns. This study tries to identify causal relationships between current ways of working and performance issues on one side and between the new model and some anticipated performance levels on the other. The relationships are established by various accuracy measures during the course of the research and are intended to be validated by simulation. Furthermore, cause and effect logic is used by applying the TOC thinking processes, which is expected to almost perfectly addressing the requirements for good levels of internal validity.

External validity addresses the generalizability of the findings resulting from one case to others in similar contexts (Yin, 2009). He continues by identifying this criterion as a major barrier in conducting case studies. Eisenhardt (1989) stresses the importance of case selection by advocating for a wide selection of cases that differ as widely as possible. Stuart el al (2002) suggest the differentiation between statistical and analytical generalization, especially when undertaking single case study research. In this study, the case of the organization is used for applying and generalizing existing theory. Furthermore, the findings leading to the new model can be used in similar industries having comparable production layout and product/volume mixes. However, this obvious possibility of further application of the ideas used needs to be seen as supporting generalizability but not proving it.

The concept of reliability has been discussed in depth previously and has been defined by Yin (2009) in the case study context as being the possibility to repeat the operations of a study and arriving at the same results. The study follows a policy that each and every data source is mentioned and referenced to when decisions or evaluations are made that lead to findings. In order to achieve reliability of performance assumptions, the calculations are laid open, so that they are ready for reconstruction and audit.

Summarizing the findings made, no issues that might endanger high levels of validity and reliability could be identified.

3.4.2 Researcher bias

The author has experience working as a professional for almost two decades. This includes leading projects that had the goal to implement ERP systems at manufacturing companies. During the years an understanding has formed that almost every situation can be modeled into a computer-based system and that in the majority of the cases the overall performance of the affected processes could be improved. Furthermore, a certain affinity for technology and the computerization of procedures should not be kept in secret. All this might endanger the validity of this study since the interpretation of the outcomes could be biased by personal opinions or paradigms.

However, the study takes place at the employer's headquarters based factory, which is the location of the office of the author. Moreover, it is one of the major projects in the sole responsibility of the author to implement a new ERP system, which includes the operations function. Therefore, a natural interest to develop something of value for the organization can be assumed. Additionally, the work to be undertaken is closely monitored by two supervisors who have no stake in the organization. Finally, the results are intended to be reviewed and approved by senior managers out of the operations area. All this could be seen as suitable ways to overcome the ensure credibility and dependability of the research results.

3.5 Data collection procedures

3.5.1 Sources of information

Since this research task is connected to a specific company for which new ways of working should be developed, main sources of information need to be selected from internal resources of the company.

Among such the researchers represents one source by walking around and undertaking personal observations. Since the personal role involves such activities quite frequently, no negative reactions or unexpected behavior needs to be considered. The resulting data is recorded in form of personal notes being produced right after observation activities to ensure high levels of reality being captured.

Another source of information is represented by management members being responsible for functions relevant to the research project. Examples for these are coming from the supply chain (e.g. procurement, logistics, production) as well as from the planning and controlling functions. They are expected to be able to explain current ways of working as well as giving reasons for current procedures.

The third source of information are foremen and operators from the shop floor because of their direct personal involvement as subject matter experts (Sproull and Nelson, 2012). It is expected that they are even better able to provide valuable details than their managers are.

Furthermore, the data to be gathered might be useful for triangulation with the findings made from other sources.

Finally, the current ERP system's database represents a source of information. Relevant data to be taken from the year 2013 as a reference for the current system's results. Furthermore, it is intended to be used as in input (i.e. demand) for a simulation of the new model to be developed.

3.5.2 Personal observation

Gaining an overview of a current system is often facilitated by a standard technique in qualitative research characterized by personal observations of the processes being implemented (Baxter and Jack, 2008 and Iacono et al., 2011). In contrast to existing process documentations or handbooks, only personal observation provides an impression of reality happening every day (Atkins and Sampson, 2002). Another advantage is its directness (Robson, 2011), which allows the researcher to simply watch what people do and listen what they are saying. He continues by highlighting the possibility to use personal observation in different stages of a research project. These can be early stages where getting an overview is sought, intermediate ones where complementary or even contrasting data is sought or later steps where verification of findings might be needed.

Beside high levels of usage and support to be found in the literature, one has to be cautious about the observer effect resulting from people knowing being observed (Webb et al., 1966). The extent to which studies are affected by this feature depends on the individual setting and the researcher's behavior, as McCall (1984) identifies this feature as being common but not universal. Furthermore, one needs to consider that this technique is rarely the primary source of data. Among many examples, researchers often combine it with personal interviews (Andrews and Andrews, 2003; Banks, Shaw and Weiss, 2007), structured questionnaires (Weiss, Feliot-Rippeault and Gaud, 2007) or with the case study method (Casey, 2007).

In this study, personal observation takes part in the early exploratory steps to gain an overview and to establish working relationships with subject matter experts. It plays a role to verify the data collected in the interviews together with functional managers and is intended to help the verification process of the new model.

3.5.3 Semi-structured Interviews

Interviews are another technique that is widely accepted and used in qualitative studies (Robson, 2011; Potter and Hepburn, 2005). They are often categorized along a depth continuum scaled from highly structured surveys over semi-structured until unstructured interviews. Following this direction, the interviewee receives more freedom and flexibility of response. However, increasing flexibility could also mean more difficult capturing of the results, especially when comparability is sought. Therefore, semi-structured interviews are used in this study acting as a compromise that allows for interaction with the interviewee to a certain degree to maximize the amount and quality of data gained. Documentation of the results is created in form of transcripts as advised by many researchers of the field as Weiss (1994) or Drever (2003).

Here, semi-structured interviews are used in the early stages of the project to gain a deeper understanding of current ways of working facilitated by a structure to ensure completeness. Moreover, the questions to be asked are not unique to each interview. This is intended to allow comparing possible different views on the same issue. Once the new model has been developed, the technique is applied again while presenting the results to the functional managers. The first reason for this is to gain an early understanding about how the results are judged by those that have to implement them. A second reason is to identify possible errors as soon as possible to be able to address them while still being in the project.

3.5.4 Internal survey

This section deals with another type of interview having a fully structured questionnaire as its basis. They are a standard instrument in research today where a certain degree of standardization or cost efficiency is required (Robson, 2011). Differences exist in the size of the population being included. This might be a small percentage in large-scale industrial surveys or on the other extreme the full population when departmental heads of a medium-sized firm represent the population. Beside the mentioned advantages, some disadvantages exist. Thus in interview survey, the interviewer might have an influence on the data in terms of interviewees refusing to provide true answers as anonymity is not guaranteed. Moreover, large-scale Internet or postal surveys might suffer from low response rates reducing the validity of the whole survey.

Since the intended interviewees are functional managers together with their subordinates, full response rates are expected to be achievable. Any form of biased answers is also expected to be low, since the interviewees know that the interviewer has the possibility to verify almost all answers by creating database queries or by comparing them with data previously generated during the research project. However, questions need to be stated in an adequate format to ensure high quality data.

The main purpose for developing and using function-specific questionnaires in this project is to capture as much detail as possible about the current processes. Individual questionnaires exist for the procurement, production and logistics function. They go deep into details while asking specific questions about the quantity structure of processes, machinery utilization, warehouse turnover and lead-times. Furthermore, critical issues like stock outs, breakdowns, quality problems and customer returns are covered. Most of the variables dealt with describing parts of current levels of performance. Some of such variables are calculated during the simulation phase of the project to offer results of the new system that people can easily compare.

3.5.5 The current ERP system

Using a database in qualitative research that offers mainly quantitative data is a common way of enriching understanding and for facilitating analysis (Stake, 1995; Yin, 2009). Baxter et al. (2008) explicitly identify the advantages as being data available for independent inspection and increased reliability. However, some disadvantages also exist mainly being the distance between the researcher and the phenomena being examined (Richards and Richards, 1994, 1998). Since the use of the database is clearly defined as complementary in the early stages and being the main input for model testing and performance measurement in the later stages, the effects of likely drawbacks can be judged as low.

In this study, the ERP database is used in two different ways. In the early stage of gaining an understanding of the current system, the database is used for verifying answers of interviewees in form of triangulation and for answering questions that appear out of the process. In the later stage of simulation of the new model, the database is the main input into the new system. Information like stock levels, customer orders, breakdowns and the like are taken from the reference year 2013 to determine the results of the new model represented by selected performance variables. The subsequent comparison of such results will conclude in a transparent and comprehensible evaluation.

3.6 Data analysis procedures

Previous sections have provided justification for undertaking single-case research and simulation. The case study should deliver a clear and full understanding of the current situation. Based on this knowledge, literature is consulted for bringing most promising ideas together with actual needs and wants from the organisation in focus of this research. Having then developed a new model for production planning and control, it needs to be tested if it can deliver what is expected. This happens by performing simulation tasks based on last year's ERP data. Throughout the analysis chapter, concepts and techniques resulting from the TOC thinking process developed by Goldratt (1994) and refined by Dettmer (2007) are used to structure the analysis. Each analysis step is described briefly.

3.6.1 Development of actual model

To be able to perform an analysis, the case needs to be described to a degree, which allows the reader to understand the justification for the later case analysis. (Eisenhardt and Graebner, 2007). Tables are used for summarising findings and for presenting additional numerical data. The case description follows the broad flow of the supply chain of procurement, production and logistics while having planning and control as a separate topic. The reason for this is that it affects all three functional parts in a dominant way. The analysis tries to identify major issues of weak performance guided by two different sources of information. First, the obvious problems and those being reported by interviewees to a certain degree are considered. Second, advice from the literature is used to uncover those issues that may not have been recognised by members of the organisation directly, which could represent even larger constraints to performance. Furthermore, it is expected that some cross-functional issues can be identified that are currently invisible to functional managers. The application of elements resulting from the TOC thinking processes is expected to ensure structure and validity of the embedded thinking and judgement. The resulting new model for production planning and control is intended to be justified by applying the aforementioned cause and effect logic.

3.6.2 Interaction with theory

The generation of initial ideas has already been influenced by a thorough consideration of the existing literature. This has led to the development of a model expected to be useful for the organisation in focus. However, the case is expected to require some modifications to this model before being able to test its potential for performance improvement. This surely helps to increase the level of internal and external validity of the findings made (Eisenhardt, 1989). The analysis chapter tries to contrast existing literature with the research findings to show degrees of fit as well as some areas of disagreement. The latter is explained on the basis of qualitative data generated during the process of research. The final result of this activity is an amended model being ready for running simulations.

3.6.3 Verification of new model

Robson (2011) identified that it is not common in single-case studies that statistical techniques are used to demonstrate the significance of effects. He summarizes the main justification for leaving sophisticated techniques out of papers by using Sidman's (1960) words that "if statistical techniques were needed to tease out any effects, then the effects were not worth bothering about". However, in operations management people work with numerical data and performance indicators on an every-day basis, which makes it crucially important to demonstrate the power of a new model by using their means of working. Plenert (2002) as well as Nock et al. (2007) provide strong accounts in favor of using numerical data and statistical techniques to show effects and their significance. For the author it is not reasonable to leave an objective source of evidence out of a study and therefore simulation activities are intended to be used. Previous sections of this chapter have already provided support for applying simulation as an extension of case study research.

Beside the main purpose of delivering something of value to the organization in focus, getting acceptance and avoiding inertia are obvious prerequisites to successfully implementing change. To allow decision-makers within the company to understand the performance of the new model in an easy way, current ways of performance measurement in form of indicators or ratios are used as one major group of evidence. These are determined during the data collection phase of the project. A second group of evidence consists of performance indicators that are suggested by the theory used. The final goal of this activity should be a model together with its performance characteristics that can be accepted or rejected based on facts rather than personal views or opinions.

3.7 The research procedure

After having described all relevant stages of the research project to be undertaken, the following Figure 17 shows the sequence and content of each stage as an overview. Each phase and the interactions with other phases are described later to provide clarity about the reasons for selecting the research instruments and the sequence shown.

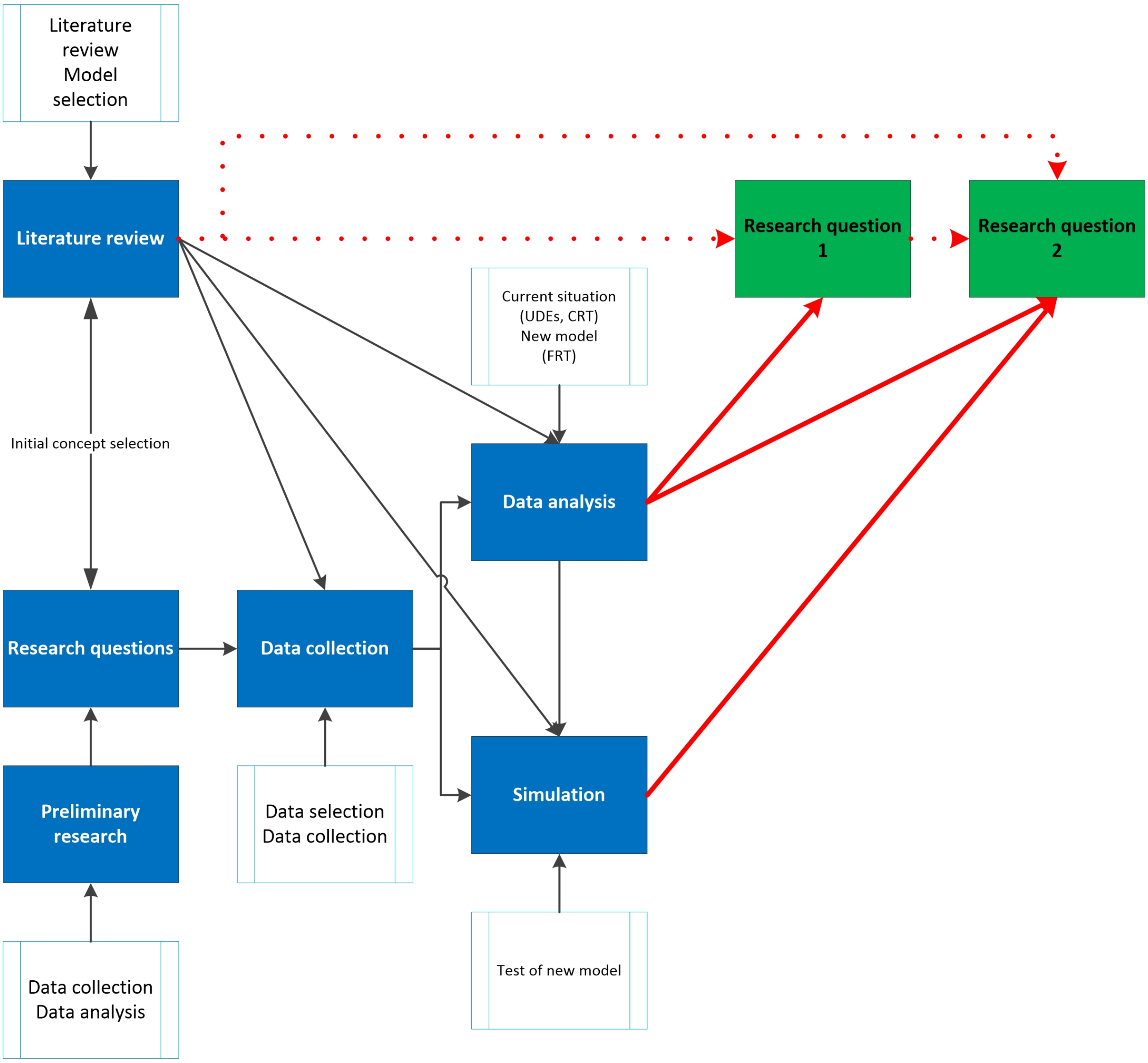

Figure 17 – Research procedure

The following sections focus on parts of the original Figure 17 in order to explain their roles as well as to provide details about the links drawn to other parts. Each part is commenced with an extract from Figure 17 showing the area to be discussed next. Connections between elements are numbered to facilitate the allocation of the discussion elements.

Preliminary research

Figure 18 – Preliminary research in detail

Figure 18 shows preliminary research activities in the middle of a sequence of activities. This research at InkCo has uncovered some significant issues that seem to limit the performance of the company. As a major result limited due date performance could have been identified. Informal data collection sometimes as by-products of taking part in regular meetings triggered this activity (2). The results formed the basis for stating the first research question that aims for a full understanding of the issues at InkCo (1).

Research questions

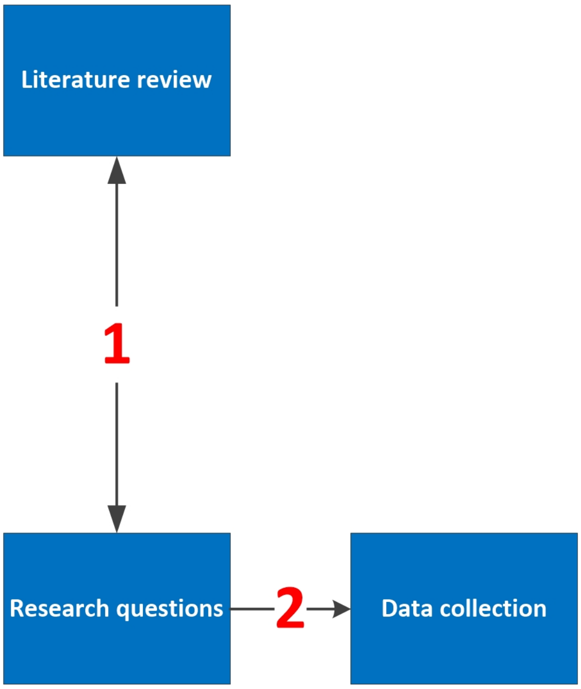

Figure 19 – Research questions in detail

As already stated, the first research question resulted from some preliminary research activities. The second research question resulted from early thinking about how to cure the symptoms InkoCo is suffering from. The selection of relevant material from the available literature and subsequent reading formed the idea of choosing DDMRP as the most promising methodology to be evaluated in this research project. The process is shown in Figure 19. Research question two is the results of this process, which addresses the value of DDMRP as well as the value of its main components or roots being MRP and TOC to name the most important ones. The link shown (1) represents therefore the interaction of research question one with the literature and the feedback in form of research question two. The resulting next step of formal data collection (2) is strongly shaped by the information needs of the two research questions mentioned.

Literature review

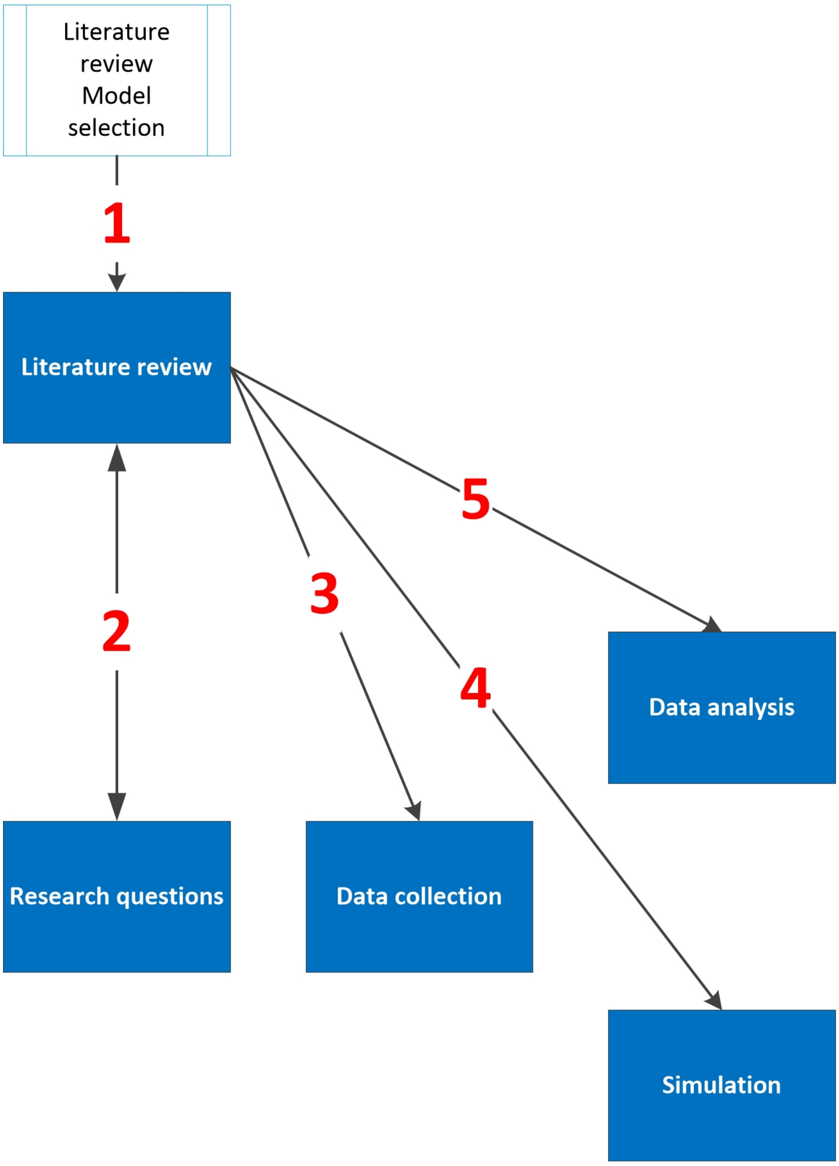

Figure 20 – Literature review in detail

Having already described the link between the literature review and the development of research question two (2) in the last section, the literature review has surely not taken place in isolation as shown in Figure 20. The link between previous literature reviews and the need to arrive at something being applicable to the case company in form of a model (1) has also shaped the content and presentation of the findings from the literature. Furthermore, the literature review had influences on the later stage of data collection (3). Examples for this result from the information needs of the TOC thinking processes to be applied to the case and from the requirements of MRP and DDMRP to be central parts of this study. The link to the later simulation activity (4) represents the fact that the DDMRP theory is intended to be applied. In a similar way, the link to the data analysis part (5) represents the guiding character of the literature on the elements of the case analysis stage.

Data collection

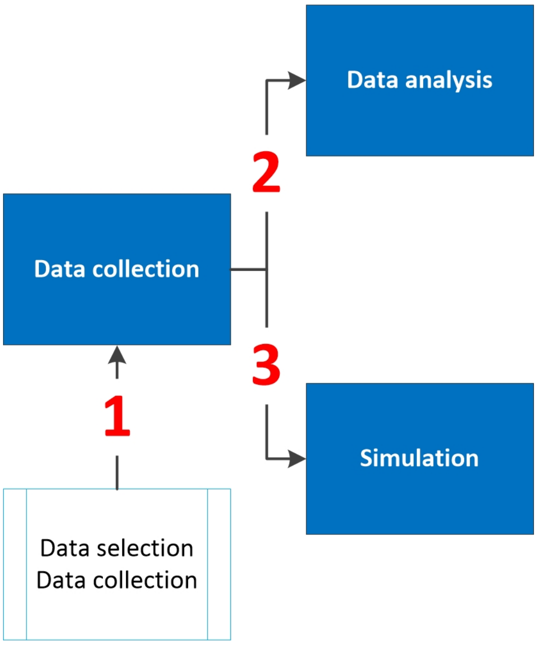

Figure 21 – Data collection in detail

Conducting research in a company needs to consider the reality of the company as well as some rules determining scope and the availability. These prerequisites had some guiding influences on the data collection stage (1). Furthermore, the previous section has identified the literature review is shaping the data collection stage as well. The resulting data of the collection stage has been used by the case analysis (2) and by the simulation activity (3). Figure 21 show the data collection together with the described interactions with other activities and phases.

Data analysis

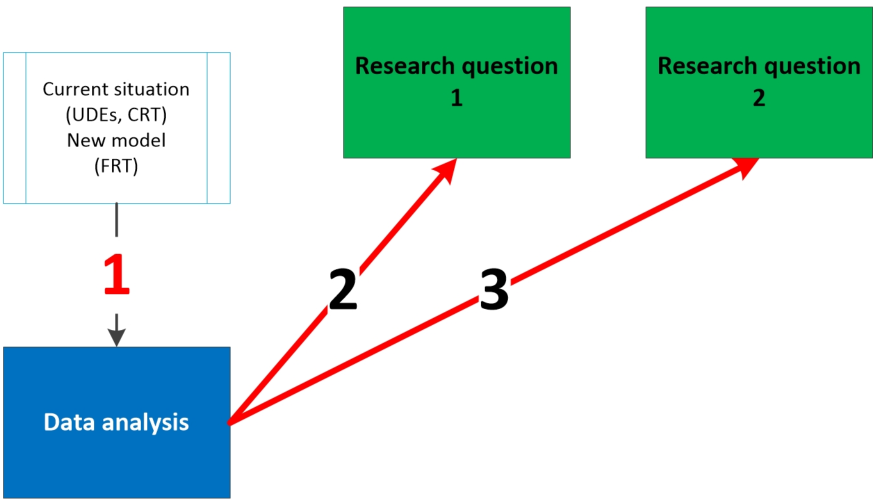

Figure 22 – Data analysis in detail

Figure 22 shows the data analysis phase together with its connections. Although being the results of the data analysis, the elements of the current and the idea of an improved situation are explicitly mentioned (1). The reason for this is that the case analysis uses these intermediate results itself for further developments. From this analysis, the answers to the first (2) and parts of the answer to the second research question (3) are developed. However, it needs to be mentioned that the literature review plays an important role, because findings from the literature are used to contrast them with case findings to show similarity as well as potential conflict. Finally, in order to undertake data analysis its data needs are completed by the following description of the simulation phase.

Simulation

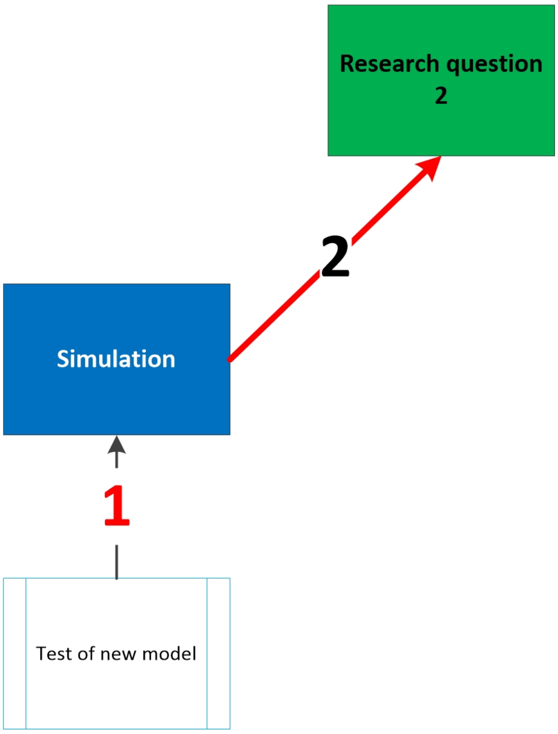

Figure 23 – Simulation in detail

A simulation that uses real company data in order to explore the potential of DDMRP to improve results has been included in the research project (see Figure 23). Parts of DDMRP are selected to be simulated (1) by using real data collected during the data collection stage. The simulation results are then used to complete the information needs of the answer to research question two (2). Furthermore, simulation results have also been included into the previously described data analysis phase to enhance the information base of the analysis.

3.8 Research activities

The research activities described in the previous parts are explained next to provide an idea about the timeline and the amount of work done. More details showing how the different methods interacted and how they helped to arrive at the required results. Although this is mainly intended to provide evidence to support the process of data collection, some data is presented at appropriate locations to provide some information about how related analysis have taken place.

Personal observation

The official start of research activities was in the fourth quarter of 2013 by formally defining the project and getting approval by the management board. To be able to understand operations at InkCo, some preliminary research was done in form of personal observation. This project phase mainly dealing with personal observation is shown in the following Figure 24.

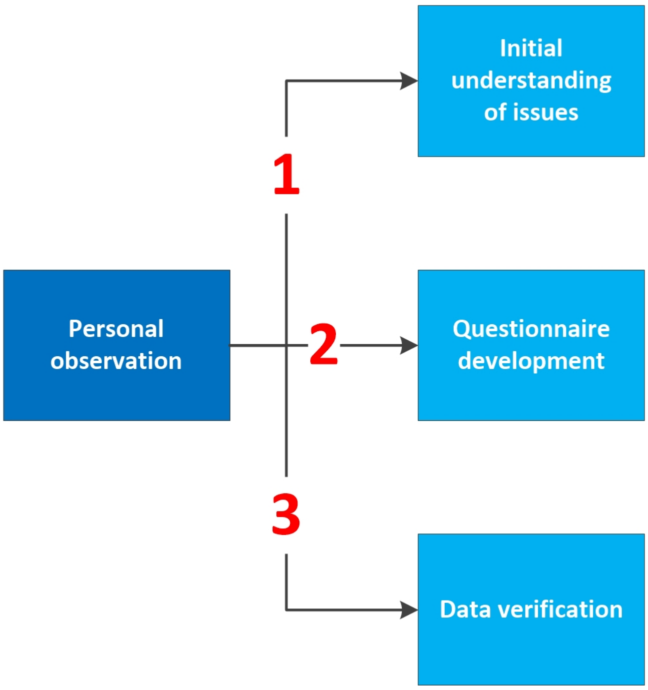

Figure 24 – Data collection methods: personal observation

Personal observation started quite early in the research project and even before, since the idea for undertaking such a project was triggered by observations made (1). Some of these early observations in form of questions are shown in the following Table 10.

1. Why is there so much WIP on the shop floor?
2. Why are stock levels for standard raw and packaging material so different from day to day?
3. What is the reason for relatively high overtime rates?
4. Why are customer complaints mentioned at most meetings?
5. Why is airfreight used widely although other methods are cheaper?

Table 10 – Early observed findings

Based on these early findings, a series of more or less deliberate observation activities took place in order to develop a better understanding about what the most important issues are that InkCo is suffering from. Based on the findings made, the need became visible that collecting a substantial amount of data would be required to be able to understand issues, reasons and dependencies. A decision was made to use internal survey as the method to arrive at the mentioned data. The questions to be asked have been derived from observations (2) as exemplarily shown in the following Table 11.

1. Value of WIP, number of work orders, due date performance, number of work orders completed as planned, expediting rate, planning horizon
2. MRP configuration, supplier performance, lead-times, variability
3. Capacity utilisation, expediting rates, plan stability, warehouse capacity, demand variability
4. Due date performance, lead-times, customer expectations, planning procedures, financial impact
5. Shipment process, stock outs, stock level planning and buffers, expediting

Table 11 – Early findings enhanced through observation

Finally, some form of observation happened during the research project on a permanent basis to allow for verification of findings made (3). As an example for such activities, one can use the procurement questionnaire. Here, the question addressing MRP proposal usage was answered positively by all participants. Some early observations unveiled the fact that this is true but that this needs more explanation. Deliberate observation uncovered that proposals are accepted but in two thirds of the cases are adjusted upwards to get a higher discount.

The schedule of this first stage of observations is shown in the following Table 12 overleaf and happened mostly in the first quarter of 2014.

Area observed	Time period	Deliberate count
Work preparation	Q1 2014 Q2 2014	3
Varnish manufacture	Q1 2014 Q2 2014	2
Pigment dispersal	Q1 2014 Q2 2014	4
Filling and packaging	Q1 2014 Q2 2014	6
Warehouse intake	Q1 2014 Q2 2014	2
Warehouse storage	Q1 2014 Q2 2014	4
Warehouse picking and dispatch	Q1 2014 Q2 2014 Q3 2014	8
Planning meetings	Q1 2014 Q2 2014 Q3 2014	12

Table 12 – Personal observation

Internal survey

The gained understanding of the tasks and objectives for each work centre shown in the previous Table 12 together with knowledge about problems and issues obtained from various sources including management meetings and even office grapevine was the basis for developing the questionnaires of the internal survey. The process is shown in the following Figure 25 overleaf.

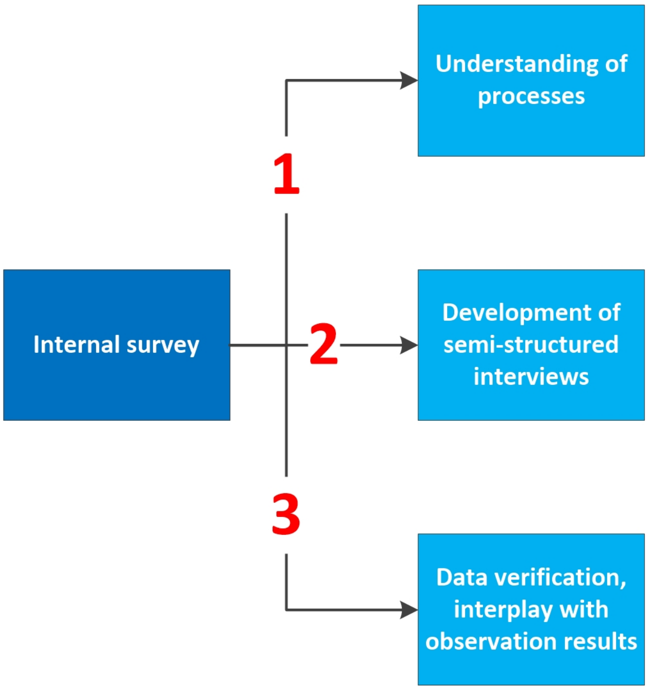

Figure 25 – Data collection methods: internal survey

The idea to undertake an internal survey was born during the main observation phase of the research project. The first purpose was to develop a fuller understanding of processes (1) including many numerical data (e.g. SKUs, work orders, purchase orders, fulfillment rates capacity utilization etc.). Furthermore, the intention was also to obtain evidence for findings made during personal observation and to uncover likely misunderstandings or even conflicting information. An example for the latter is the fact that through observation clear evidence was obtainable that MRP is widely used, but the survey delivered information that MRP is only used for finished products planning. This example is also useful for explaining the data verification purpose of the internal survey (3). Finally, the results of the survey prepared the ground for undertaking semi-structured interviews (2). In many areas the facts were clear but reasons for them seemed to be necessary for understanding them. Reconsidering the MRP usage example makes this clear: There must be a reason for this only partial implementation. Furthermore, the data collected acted not only as an indicator for further questions but also as a knowledge base helpful for asking better questions in the next stage. The questionnaires are shown in Appendices 5 to 8 of this document.

Actvities undertaken for completing the internal survey are listed in the next Table 13 overleaf. They have been sent out to managers responsible for the respective function to be completed within a two weeks timeframe. The reason for sending the questionnaires not only to the head of the department but involving more managers was to allow for crosschecking of the results.

Function	Questionnaire	Time period	People involved	Return rate
Procurement	Procurement (Appendix 5)	Q1 2014	4	75%
Production	Production (Appendix 6)	Q1 2014	3	100%
Logistics	Logistics (Appendix 7)	Q1 2014	4	75%
Planning	Planning (Appendix 8)	Q1 2014	4	75%

Table 13 – Internal survey

One might wonder why such high return rates have been achieved. The obvious reason for this is that it was an activity announced and supported by top management. Another reason becomes clear when taking a closer look at the questionnaires. They have not only been designed to contain supply chain optimisation relevant questions. People were given the chance to reflect about their current ways of working and to make suggestions about various forms of improvement. Later conversations with participants supported that initial assumption. They reported that they were only rarely asked to identify improvement opportunities and that they found it a challenging but also stimulating activity to think about their ways of working in such a detailed way.

Semi-structured interviews

The results in form of the returned questionnaires for each function were merged into one single document per function. During this task, areas of congruence and variety of answers were identified in preparation of a series of workshops. These workshops were designed to happen on two consecutive days in the weeks shown in the next Table 14 overleaf. The same people were invited that already have completed the questionnaires to discuss the results. However, the main focus was set to the areas where congruence was not visible from the questionnaires. Sometimes a unique result could have been achieved by discussing the topics and by resolving any issues resulting from misinterpretations. In rare cases, significant amounts of time were needed to achieve a compromise. Nevertheless, all participants had again a chance to discuss workplace related subjects in a quite isolated environment that allowed for creativity. At the end of each workshop when people were expected to have developed there "new future", the formal interview was conducted as shown in Table 14.

Interviewee	Aide-mémoire	Date	Duration (min)	Recording method	Storage
Procurement	Procurement (Appendix 1)	Week 9 2014	52	Personal notes	Summary minutes
Production	Production (Appendix 2)	Week 7 2014	48	Digital voice	Transcript
Logistics/Sales	Logistics/Sales (Appendix 3)	Week 8 2014	71	Personal notes	Summary minutes
Planning	Planning (Appendix 4)	Week 10 2014	76	Digital voice	Transcript

Table 14 – Semi-structured interviews

After having uncovered some obvious issues that limit the performance of InkCo through personal observation and the series of workshops and having collected a significant amount of data describing current ways of working and enhancing the understanding by providing numerical data, the semi-structured interviews could be undertaken as shown in the following Figure 26.

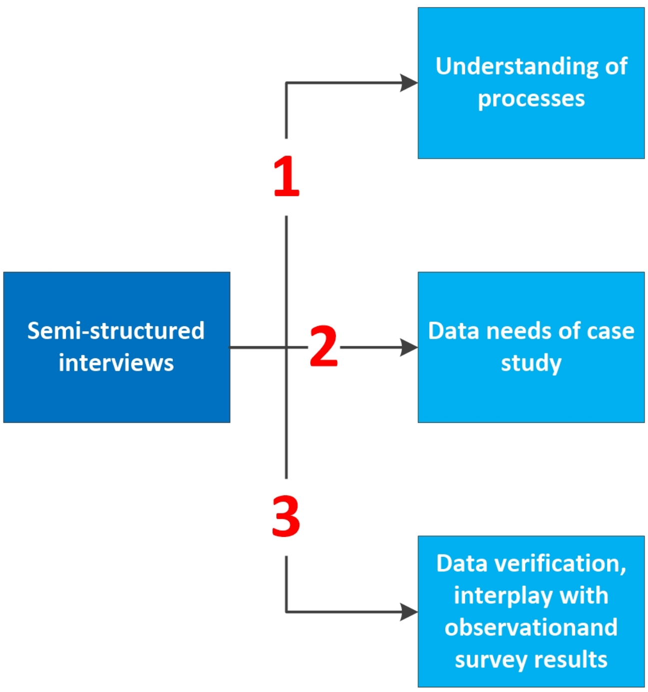

Figure 26 – Data collection methods: semi-structured interviews

Special attention was paid to the information needs about the reasons for answers given in the survey and likely conflicts being detected shaped the interviews only partially structured by the aide-mémoires shown in Appendices 1 to 4 of this document. This allowed for ensuring completeness as well for flexibility to concentrate on unexpected areas. All this explains the first purpose of this stage being the development of an almost full understanding of the current ways of working (1), including facts, reasons for them and issues. The latter leads to the second purpose of the interviews in form of satisfying the data needs of the case study to be produced (2). Since it forms the basis for answering the first research question, special focus was set to identifying and exploring performance limiting issues. Finally, verification of data obtained in previous stages was also a purpose of the interviews. Some form of triangulation of the findings was used to dig deeper in order to arrive at the truth. An example for this related to the translation of the annual forecast into a MPS is shown in the next Table 15.

Observation:
MPS does not reflect the reality of production planning
Manual translation of target revenues into Min-Max configurations and monthly MPS demand figures
Survey:
Reliability of planning and embodied tools questioned
High levels of expediting due to plan changes
Wish for reliable production schedules
Semi-structured interviews
Sales budgets are aggregated too high and include optimism. Translation into MPS figures is mainly based on manual procedures and individual experience
Adjustments to Min-Max configurations are time consuming and often neglected
Manual planning of intermediates' demand on the BOM levels except the finished goods is often a rough guess
Misaligned stock configuration is the main source for expediting and changes
Synchronisation between sales activities and current load is lacking
Lead-times are too long due to batch sizes larger than needed
Only 10% of work orders finish as originally planned
Performance measurement encourages "wrong" behaviour

Table 15 – Data analysis and triangulation in practice

On the basis of the merged and amended questionnaires and the interviews, the case study could be produced. Parts of it have been shown to interviewees for verification and to continue to show them that participation is really sought. Although this procedure is not common at InkCo and things like case and effect diagrams or logic trees were quite new to most of the interviewees, the whole bunch of activities was seen as beneficial to InkCo.

Database queries

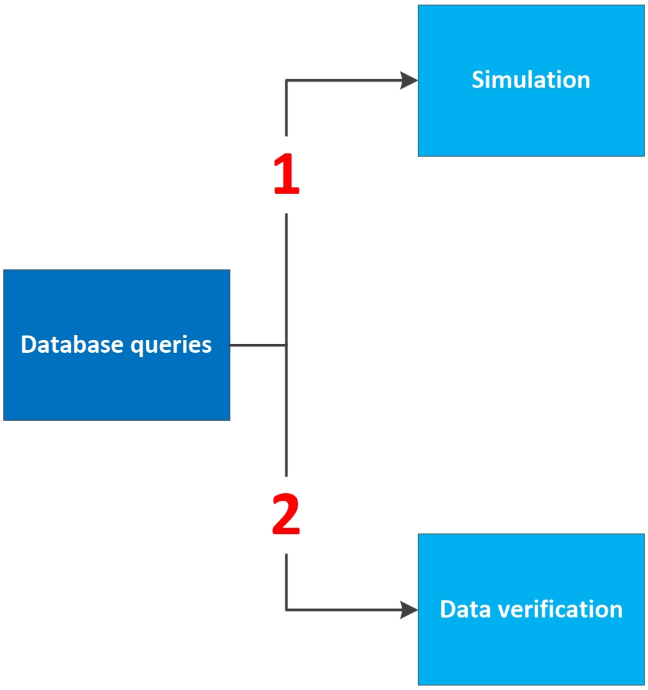

Figure 27 – Data collection methods: database queries

The database of the current ERP system was used for two main purposes as shown in Figure 27. First, to extract data in the area of demand (e.g. quantities and variability), stock levels (e.g. on-hand stock, stock performance indicators) and production (e.g. lead-time) required for the distinct simulation activity (1). Examples for the data extracted and its usage can be found in Appendices 10, 11 and 12. The second purpose of using the existing database was to verify observations made in personal or derived from the surveys and answers given by interviewees (2). As an example for the verification of observations one planning meeting in the first quarter of 2014 can be used. Managers from production and planning were complaining about the huge demand resulting from customer orders that would result in an unrealistic capacity utilization of about 150%. A few database queries showed that only one third of the open work orders were directly allocable to specific customer orders and the remaining ones were intended for filling up stock. Furthermore, roughly one half of this stock replenishment would have had the result of stock levels far too high to be justified. A question the database could not answer was posed to the planning manager trying to uncover the reason for this waste of resources. The answer was that performance measurement focuses on output and machinery usage and that this is the reason for reducing setups and cleanings whenever possible.

A final thought should be made about the role of the researcher in this series of activities while considering the identification of likely bias made previously. Significant possibilities to influence activities and later results have always existed during each stage since the author has designed the questionnaires, has selected participants for each functional group, chaired the workshops and conducted the later interviews. In contrast to these possible threats to objectivity, an ever-present impression that participation and involvement by functional experts was sought might have helped to reduce any impact. Moreover, it was a common theme throughout each stage that people were invited to provide their views and to design their new ways of working. Since their feedback was mostly positive it is likely that it has really happened to a large extent.

3.9 Conclusions

This chapter started with a breakdown of the two research questions into more manageable sub-questions that also allow the reader a better understanding of the targeted content. A discussion of the main epistemological directions concluded with a justification for choosing and applying a realist approach throughout this study.

A brief review of qualitative and quantitative study methods leads to the justification of single-case study research together with a simulation approach being appropriate for this research project. Since purely qualitative or quantitative methods seem not to be sufficient to this study, the mixed-mode strategy incorporating valuable elements from both categories is explained and justified. The selection is mainly influenced by the practical focus of this research activity and represents a goal-focused compromise that tries to mitigate any limitations.

Relevant instruments of this study are presented briefly followed by an evaluation of the study design. Adequate levels of reliability and validity can be attested to this study, which proves the design to be appropriate in line with the study needs. A brief discussion about likely researcher bias shows limitations as well as ideas to limit their effects.

Concentrating on the data needs of the study, the main sources and ways of collecting the data are presented. Mixing of methods like personal observation, semi-structured interviews, small-scale surveys and databases could have the potential to enhance the quality of the later case study description and analysis. The case findings together with real data from the case company's databases act as an optimal input into the simulation activity, which succeeds the case analysis.

The final stage of developing the answers to the research questions is a multi-staged process. First, the case is produced and analysed which acts as the main source for answering the first research question. Second, the case analysis' result in form of a new model for production planning and control is tested in the simulation activity described. Both results are then used to develop the answer to the second research question. Especially the evaluation of the model done during the simulation is intended to show its potential for performance improvement based on facts.

A concluding summary of the research procedure puts all parts of the chapter together in order to facilitate understanding of the whole project. The final presentation of the research activities that have happened in reality is intended to show data collection activities and to provide justifications for the tools applied.

4 Case analysis

4.1 Introduction

The purpose of this chapter is to identify an appropriate system for production planning and control for InkCo. It does so by introducing the case company in general by describing its industry and products. Further on, its organisational features and the manufacturing function are analysed. Special attention is given to forecasting and planning as it is implemented today. Finally, special focus is also set to the current supply chain implementation. All this represents the basis from which the initial situation can be understood as well as undesirable effects (UDEs) can be identified. By doing this, the required information is produced in order to develop an answer to research question one in a later chapter. In an attempt of analysis of such UDEs, areas of improvement are identified and depicted in form of a future reality tree showing the plan for improving the firm's performance. Following this, the introduction of DDMRP is prepared by stating the work to be undertaken as well as mentioning some requirements to be considered. Final conclusion shall summarise the findings made and should fulfil a bridging function to the analysis chapter of this document.

4.2 The case company

The company in focus of this case study is called InkCo. It has its headquarters in Germany for more than 150 years and offers high quality inks for screen, pad and digital printing applications as well as liquid coatings to customers in about 80 countries all over the world. InkCo's track record of innovation stretches back over more than 60 years, featuring many industry-first solutions for both industrial applications and graphic design. The distribution in Germany is organised together with exclusive partners and worldwide via its subsidiaries. The subsidiaries' function is not only sales and distribution since most of them also perform production activities ranging from colour mixing to digital ink manufacturing for which they hold stock shipped directly from Germany.

The main means of control is the annual budget, which is developed every year at the end of the third quarter on a worldwide basis. It contains detailed sales plans on the basis of turnover per SKU group (i.e. product line), resulting operational costs and investments. Once agreed, functional units including procurement, production, logistics and sales have a certain degree of freedom being only subject to monthly reporting. Moreover, reporting focuses mainly on deviations from the budget, which is reviewed and amended twice during the year (ends of 2nd and 3rd quarter) to allow for consideration of any unforeseen needs for adaptation. The case research focuses on the major plant in Germany being able to produce almost all SKUs and having all functional departments closely related to its daily operations.

An overview of the whole process chain is provided in Figure 28 to facilitate understanding of specific functions and interrelationships.

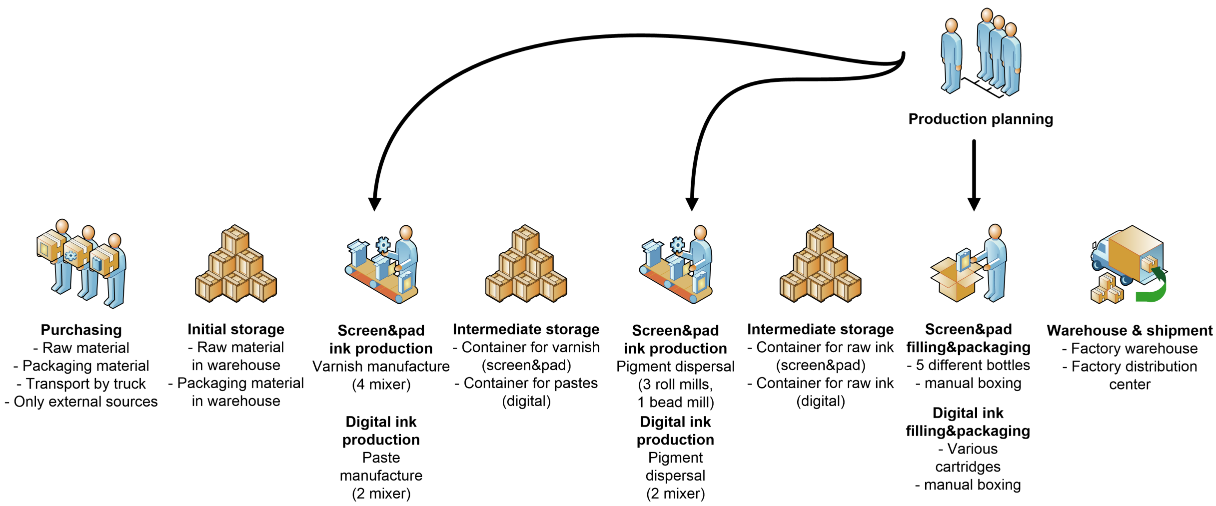

Figure 28 – InkCo's supply chain

Before moving the focus from the general company facts to more specific subjects, some important quantitative information from the 2013 figures are presented to round off the picture of InkCo. These are shown in the following Table 16.

Business segments	# SKUs	% MTO	% Revenue
Screen printing	3,500	12	64
Pad printing	1,200	18	22
Digital printing	500	3	12
Total	5,200	12.5	100

Table 16 – InkCo company facts

4.3 Forecasting and demand planning

The basis for production planning and control and related decision-making is often the annual sales budget, which is then translated into the MPS as the main information being used by classic MRP. Since the sales budget is made well before the actual year in focus, reality requires the implementation of adjustments to better reflect real customer demand. However, theory suggests that even the best plan will turn out to be incorrect, especially in the short-term focus of operational decision-making. Here, another mode of planning needs to be used that tries to establish a compromise between urgency and stability. All three planning methods are described as they are implemented at InkCo.

4.3.1 Annual budget

The annual budgeting process starts early in September with the goal of having a budget agreed and established at the end of the following October. It is in the main responsibility of product management to review the current year's budget and to apply different techniques to the figures in order to arrive at the next year's goals. These techniques include historic figures plus a percentage of improvement, implementing positive or negative adjustments to reflect the life cycle specific to individual product lines or setting targets resulting from sales objectives imposed by top management. At the end of all the activities stands the sales budget for standard product lines showing target revenues on different levels of the product hierarchy depending on the level of detail one is willing to show. This means that for long-term established products with expected low levels of volatility a figure is shown on higher levels of the hierarchy while for newer or more volatile product ranges a more detailed breakdown is calculated.

While the procedures described above are valid for standard products, InkCo follows a different approach for recently developed products being new to the company or even new to the whole market. Here, so-called key actions are planned, which represent large projects that contain expected sales as well as various forms of cost including manufacturing, development, promotional activities and the like. The sales budget is determined on the basis of expectations or forecasts that are informed by knowledge of the market, already existing distribution contracts and sales targets. Figures are mainly shown on the level of product line with only a few exceptions that go down to the SKU level. Recent budget reviews have provided the perception that the figures are far from being as stable as those for standard products, which could be proven by deviations of two-digit percentages. Nevertheless, less reliable budgets for such new products are accepted due to the potential some of them might have once they become well-established standard products of InkCo.

While the first two categories follow an MTS style, another type of budget determination is applied to the remaining category of MTO products. They include inks that are mixed from already existing inks following a customer agreed formula and new development targeted at niche markets that only require small quantities. All of them have the characteristic in common that future demand is not foreseeable or even allocable to specific SKUs. Therefore, the budget contains target revenues on different levels of the product hierarchy depending on the amount of knowledge available.

All these three approaches are then integrated into the annual sales budget that shows revenue figures on different levels of the product hierarchy for all markets around the world. This budget includes sales to be realised through the national distributor network, sales being made to direct (i.e. industrial) customers and those being made through subsidiaries. The latter are seen to be important drivers of InkCo's global operations. Therefore, their individual budgets based on deeper and often more valid knowledge of the local markets in their focus are used to verify the headquarters' assumptions and sometimes also to justify amendments.

At the end of October a global sales budget containing only revenues and not sales in form of quantities on the level of SKU's or product hierarchy level totals is ready for top management approval. It needs to be stated that the main purpose of the budget is financial control and not manufacturing. A direct translation of anticipated revenues into quantities is not possible shown by one of the interviewees saying: "If you sell the same ten products to ten different customers you automatically arrive at ten different prices." Therefore, consideration of capacity in manufacturing or warehouse areas is explicitly not part of the exercise. Moreover, it is simply assumed that it is possible to produce what has been planned. Another proof for the negligence of the manufacturing function is the fact that until final approval of the budget no participation would be sought.

4.3.2 Adjustments during the year

As already described, all plans might be wrong due to unforeseeable changes of the markets or customer demands. Especially when operating on a worldwide basis, plans are affected by the state and development of national economies or global influences as foreign exchange rates, import duties and the like. Moreover, even well known customers might change their attitudes towards products and technologies that directly influence levels of sales. To be able to consider all these factors into the company budget, two review activities are fixed at the end of the 2nd and 3rd quarter.

On both fixed dates, product management together with sales reviews the past performance of the current year against the budget. If information is available that explains any deviation the budget might be reduced in cases when the current trend is expected to continue or it might be kept as one expects increased sales in the months to come. In absence of any specific information the past performance is analysed and the budget adjusted accordingly. There are cases when the budget has not been reached during the past month but it is judged as possible to catch up. In such cases it is common that sales activities are agreed, which are seen as supportive for achieving the goals.

At the end of both activities one finds an updated sales budget that contains again revenue figures at different levels of the product hierarchy. The main purpose is still financial control and anticipated earnings figures to be shown to different stakeholders. Any form of consideration of manufacturing performance or needs is not part of the procedures.

4.3.3 From budgets to actual demand

The previous section has already explained that annual budgeting delivers only revenue figures. Moreover, the difficulty to calculate planned quantities on the basis of revenue figures being the result of many price and quantity combinations has been mentioned. However, a master production schedule is needed to allow MRP to determine material requirements and to create planned production orders. The development of the MPS is explained for standard and new products next.

Standard products that often have a history of many years are viewed as behaving every year in a similar way. This means that last year's monthly quantities are multiplied by the difference derived from comparing last year's budget revenue with the actual one on a monthly basis. This procedure is well embedded into ways of working in production planning and control, although many deviations from this plan are common but also accepted. For products that face a net change of more than five percent, safety stock is also adjusted. For new items the quantities are determined by dividing the monthly revenue figures by an average price. This is rather possible here than for standard products since the customer base is expected to start to grow slowly and quantities are still small compared to standard products. In cases where no specific information about the spread of SKUs within product groups is available, uniform distribution is assumed. The calculation of safety stock for new items is often seen as an activity not necessary. Reasons for this include the fact that minimum lot sizes often provide the demand of many months and that budgets for such products are always incorrect.

Having now explained the MPS determination for MTS style products, the MTO category needs to be explained. The products that fall into this category are often needed in very small quantities compared to the lot sizes for standard products. However, as they need finished products if colour mixing is involved, low stock levels of the required products might trigger larger production orders in preparation of the actual mixing activity. Moreover, in cases where ink is produced according to a customer-specific formula, manufacturing resources are needed that might be already utilised by the production of standard products. The resulting conflict is treated by expediting or by working overtime.

Having now discussed the prerequisites of planning and developing a MPS, the focus is set to operational planning and production control. MRP is currently configured to focus on the requirements for finished products only. It runs once a working day to generate a production proposal list that includes a line per SKU that has a calculated net requirement today or in the near future (i.e. 3 month ahead of today). It is the job of production planners to identify the products needed and to determine an adequate lot size. Decisions are often influenced by work experience and the overall aim to be as efficient as possible. The last fact is supported by uptime and total output figures per week and per month being visible all over the production area. The MRP proposal list is reviewed every day in order to avoid any stock outs resulting from unexpectedly high order intake. However, the formal planning meeting is scheduled every Thursday morning and has the objective of fixing a production schedule for the week ahead.

The demand for the SKUs to be produced is determined based on the MRP proposal and manual adjustments due to production specific knowledge (e.g. optimal order sizes, anticipated demand, etc.). After that, a manual calculation of the resulting upstream demand of semi-finished goods and raw materials is made to check if the resulting production orders for these items are viable in terms of capacity and raw material availability. If everything is possible, the plan is released; otherwise adjustments are made and verified in often more than one cycle to arrive at the final production schedule for the next week. Since raw materials are planned according to an order point system and have a replenishment lead-time of commonly more than one week, their availability is often a limiting factor. Furthermore, capacity issues can only be compensated for by working overtime or by working an additional shift on Saturday morning, which is limited by legal and work council regulations. Finally, as the demand for MTO products is not fully visible at this stage, changes of the schedule during the week are a common fact.

4.4 Supply chain implementation

The supply chain at InkCo roughly follows a V-shape although the V needs to be seen as quite sharp and narrow. All starts with the varnish manufacture that is stored in containers for later usage by the next step of pigment dispersal or paste production. There is a certain variety of varnish to be produced depending on the finished product's requirements, but only in two digit quantities. The relationship of usage of varnish by intermediate productions of raw ink or paste can be characterised by 1:n. The next step, which also follows a 1:n relationship, is the filling of raw ink or pastes into the final packages (e.g. bottles, cartridges or buckets). It is quite common that raw ink is filled into up to five different packages during one intermediate batch.

Since varnish or pastes can be used for different inks, it happens quite often that an urgent work order uses the varnish that has been produced for another ink. The result would be shortages on the SKU that cannot be produced due to the lack of varnish. On the other hand, it is also common that significant amounts of varnish are stored in containers because the required mills for the pigment dispersal step are not ready. Synchronisation of the different production steps is neither implemented nor appreciated, because performance measurement of the different departments is fully output-orientated.

4.4.1 Procurement

The task of the procurement function is to ensure availability of raw and packaging material according to the needs of planning and production. Long-term contracts are negotiated with vendors on the basis of the annual sales budget translated into the specific materials by consulting the bill of material. Demand for all materials is shown on an order proposal report generated by the ERP system. It considers actual demand resulting from open work orders and demand resulting from stock levels being below the configured minimum value. The latter represents a source of problems because most of the times minimum and maximum stock figures are determined once the material is created in to the ERP system and will only rarely receive an update. Furthermore, demand is occasionally reported by members of production or sales by telephone or email in cases where the decision to create work orders has not yet been made. Once the demand is recognised, the suggested quantity can be accepted or edited to arrive at the final purchase order. The ERP systems helps to find a suitable supplier by using material and vendor master data as well as price information. The described procedure is a daily activity although more purchase orders are created at the end of the week. The reason for this is the fact that Thursdays the production schedule for the following week is fixed and resulting work orders are created into the system. Since changes appear almost constantly, vendor lead-times varying from a few days to a few weeks depending on the material require frequent expediting and schedule changes. Sometimes even stock-outs affecting chemicals and packaging material causing delayed productions or even stock-outs of finished goods exist. Another source of problems is material quality that is measured during mandatory quality inspection. If the material fails to comply with defined quality parameters it will be sent back to the supplier. The result is material shortage and production schedule changes that may end up with stock outs of finished goods. A common measure to alleviate the effects is to simply order higher quantities than required and thus building buffers. This occasionally turns the warehouse for chemicals and packaging material into a bottleneck due to the limited space available. Being directly asked why there is no visible change initiative in place that tries to address the lead-time and the quality problem, managers in charge claim that their manual work consumes most of their time, which leaves no space for such time-consuming initiatives.

4.4.2 Ink production

InkCo produces inks for screen and pad printing as well as for digital printing applications. For all inks the manufacturing process starts with the production of varnish (a mixture of solvent, resins and additives) and then pigments are mixed into it.

Varnish is a liquid that binds the pigments to the printed surface and therefore provides the printability of the ink. There are two main kinds of varnish being oleoresinous and non-oleoresinous. InkCo only produces the latter, which are mainly based on resin. They are manufactured by breaking up the resin particles and dissolving them in a solvent in either a cavitation or rotor mixer. Cavitation mixers consist of a saw tooth disc on a driven shaft and can operate at variable levels of speed. They are mostly used when high viscosity resins are involved. Rotor mixers operate at a fixed speed and are mainly used for low-level viscosity resins due to the low agitation in the mixer compared with cavitation technology.

Once the varnish is ready, the pigment needs to be mixed into it to arrive at raw ink in the case of screen and pad printing products or at the paste for digital inks. InkCo uses two main types of equipment for the first two categories, which is chosen depending on the batch size, the tack or stickiness and rheology of the ink. The classic technology is the three-roll mill that consists of a series of cambered rollers rotating in opposite direction. The pigment particles are fed into a hopper above the two rear-most rollers and are dispersed by the shear forces between the rollers. The rollers are water cooled to reduce the build-up of frictional heat. The second and more advance technology in terms of the possible throughput is a bead mill. It consists of a cylindrical chamber filled with beads (the charge) and surrounded by a water jacket for cooling. Varnish and pigment clumps are pumped into the chamber and the charge is set into motion by a series of spinning discs. The charge grinds the ink, breaks up the pigment clumps and disperses the ink evenly. At the end of the process, the ink flows out of the chamber through a sieve and the charge remains for re-usage. For the remaining category of digital inks the aforementioned cavitation mixers are used to disperse pigments into the pastes.

Finally, the raw ink needs to be filled into appropriate containers to form the finished product. These vary from metal tins for screen printing inks over plastic bottles for pad printing inks until printing cartridges for digital inks. The filling process is automated for the first two categories and manual for the last one. At the end of the filling process, the finished goods are put into cases and are moved into the warehouse by fork-lifters.

Since customers require high levels of quality, permanent inspection and control is a crucially important activity. After varnish manufacturing the product is blocked into the system preventing work orders from using it. Quality inspection takes a sample and performs predefined inspection tasks depending on the material. The result can be one out of three different states. If all parameters could have been proved to be within normal ranges the varnish is released for further usage. Once one or more parameters are out of expected ranges a decision is made if rework would have a chance to solve the problems. If rework is the decision, the varnish is moved back into production and a rework recipe is applied. In rare cases when rework cannot be justified, the varnish is wasted and a new work order needs to be created. Exactly the same procedures are applied after the pigment dispersal stage, although parameters to be tested are obviously different. For all batches of raw ink that are released into the filling stage, a sample is kept and stored over the shelf life of the ink to be able to verify any customer complaints that might arrive at InkCo's service desk.

4.4.3 Logistics and sales

The business is organised through gross sellers in Germany that also represent the major German customers. This represents roughly 20% of the business, which leaves the remaining 80% of the business happening outside of Germany. This is organised through InkCo's subsidiaries that are also treated as customers comparable to the gross sellers. Orders are received every working day and are then created into the ERP system. Although no specific lead-time has been agreed with customers or subsidiaries, two days in Germany and periods of up to two weeks depending on the destination and the method of shipment (e.g. sea or air freight) for subsidiaries are common intervals. After the sales order is created, availability of the required SKUs is verified. Current ways of working assume permanent availability and immediate response time for the MTS line of goods (85%). The customer is only informed if SKUs are not available. The communicated estimation of availability is based on experience. The same is true for the MTO line of products (15%). The communicated expected shipment date is verified by involving the production department. Although, the concrete order intake in terms of SKUs and amounts cannot be anticipated, over a monthly or two-monthly period the demand can be reliably forecasted.

After the order is created it is released to the warehouse. An existing schedule of shipments (e.g. Northern Germany every Tuesday, France every Wednesday and Friday) dictates the date when the picking needs to be finished. If material is not available or picking could not be completed by the time the truck departs, it will be allocated to the next shipment into the specific region.

4.5 The current situation

Based on the preceding description of the procedures and ways of working in the areas important to the production planning and control function, an in-depth analysis using the TOC thinking processes is intended to identify a set of undesirable effects of the current system. This represents the basis for developing an improvement plan and for verifying its potential to alleviate negative effects and to provide answers to the questions of what to change, to what to change to and how to implement the change.

Planning and control

The discussion of the steps that are necessary to translate the annual budget into concrete demand figures has shown that the current minimum and maximum settings are nothing more than informed guesses. A planning manager confirmed that there is not enough time for them and helpful tools are missing for adjusting such parameters to reflect current reality. “They are keyed in once an SKU is born and stay there untouched until dramatic deviation is identified” this manager describes the situation.

Another problem is the inadequate usage of the current MRP module. It is only used to generate proposals for finished goods rather than creating them also for intermediate products. “We are using Excel and a lot of experience to arrive at our intermediates’ demand, because the system cannot do more for us” a planning team member identified their problem. He continued by saying that “the permanent need to change plans does further deteriorate our required intermediate and raw stocks.” The resulting manual work beside all efforts delivers often only sub-optimal results.

Additionally, the performance of the production function is measured by focussing on output figures of finished goods. This encourages planners to minimize “unproductive” times caused by setup and cleaning. The result is batch sizes often too high in relation to actual demand (see SKUs in chapter 5). The planning manager complained by asking “how can we justify reducing batch size for which we will be punished immediately”.

Furthermore, inadequate translations of sales budgets into demand (i.e. MPS construction) together with problems resulting from miscalculated intermediate demand leads to conflicting priorities. Work order priorities and quantities are than changed on a permanent basis and intermediates are “stolen” away to satisfy the demand of more urgent productions. “Only 10% of work orders come as planed”, the planning manager confirmed a figure that was reproducible from the ERP data. Sometimes even products categorised as MTS are produced according to MTO principles to satisfy actual demand.

Another source of problems is represented by quality and its control. After the stages of varnish production and pigment dispersal the mandatory quality inspection happens. This needs to be seen as a potential bottleneck, since material can only continue its flow once being approved. Although no reliable statistics exist for confirming this, the procurement manager acknowledged the existence of this problem and continues by identifying that "there is not enough time for us to go deeper into this issue. Our main job is to ensure that materials are available given the enormous amount of changes to our plans." While this quote reflects reality, it is surely influenced by personal goals and opinions. On the other hand first-pass yield is closely monitored and established well above 95%.

Finally, the previously mentioned frequent changes of production orders and related priorities have another undesirable result. Thus, resources as mills or mixers are often unavailable for scheduled work orders, because they are currently used or need to be cleaned to become available again. Further changes to the plan, expediting and sometimes overtime are common answers.

Inventory

Based on the operational planning, finished goods are produced in quantities that are often not connected to or justified by actual demand. This leads to inventory items with too much stock on one hand and to those with lower stock levels than needed on the other (see the SKUs in chapter 6 for more details). The resulting instability of the whole system leads to expediting and shifting priorities, a situation the planning manager describes as "chaos". Contrary to this is the fact that significant quantities need to be devalued every year due to shelf life or long-range issues. An overall impression gets manifested that overall high stock levels seem to support still acceptable due date performance levels at a significant cost while they are not sufficient for all situations.

Although standard raw and packaging materials with regular consumption are available at the warehouse, stock outs or stock levels too low for intended productions are a common feature. The inadequate usage of the existing MRP together with manual tools delivering only suboptimal results represents a problem. Furthermore, materials are only ordered if they hit the safety stock barrier or if specific information is available from sales or production, which might be too late for urgently needed productions. One reason for ordering that late represents performance measurement criteria relevant to the procurement function. Good performance is defined by using volume related discounts wherever possible to keep cost down on one hand and to limit the overall ordered quantity down to what is really needed. The procurement manager described this situation in a harsh way by coining that "they want from us to fit a square peg into a round hole, which we simply cannot deliver". Another problem is that lead-times resulting from the Thursday fixing (see previous subchapter) are often too short for suppliers to react on time.

Logistics

Since stock outs are a common problem, it is often not possible to ship an order in total to the customer. Missing items are then shipped once available by the fastest method available. Increased freight cost (e.g. air instead of sea freight) and disturbance of normal warehouse operations are a likely consequence.

Sales

It has already been said that the creation of budgets has financial control as its primary purpose. Since production planning needs a MPS, they try very hard to translate revenue figures down to SKUs and quantities. However, these forecasts often turn out to be inaccurate, which requires adjustments and also changes to the current production plan in presence of urgent demand. The aforementioned budget reviews and individual ambition and sometimes luck on the side of sales managers unearth unanticipated orders and resulting demand for products. On a regular basis sales managers do not take into account the current production load or on-hand stock while accepting customer required delivery dates. It is a common understanding in sales that "we do our job and they should do their job", as one sales region manager said. The resulting expediting activities and oscillating priorities between urgent orders and stock replenishment are almost obvious.

Tools

Previous paragraphs have already highlighted the fact that the current MRP functionality is only used for finished products. Work orders for intermediate components are calculated and created manually. Tools used for this task are self-made by the planning team by involving applications such as Microsoft Excel® and Access®. The resulting problems are described by the planning team as follows: "We have to define a time when we have to transfer information from the ERP into our Excels. This is always a wrong decision given the permanent changes. Therefore, we are basing our decisions quite often on wrong data."

Furthermore, inadequate stock management configurations (i.e. Min/Max) are ignored and instead self-developed planning solutions are used (i.e. based on experience and grapevine). However, the so-called chaos is the prevalent mode of operation.

The previous description of the current situation was analysed initially arriving eleven UDEs that characterised the situation well enough. However, they have been found to be interrelated and also overlapping to an extent, which made it necessary to condense them down to a more manageable number of six. The following Table 17 lists the UDEs together with explanations derived from the previous parts of this subchapter to allow for recognition of the related features. Additional examples taken from the primary research are intended to facilitate understanding and acceptance.

Case UDE	Case examples
There are frequent shortages of finished goods (**UDE #1**)	• Annual budget is treated as the only truth, which it is obviously not. The resulting self-constructed MPS is often misleading. • Forecasting is seen as an universal solution to demand determination and production planning • Reality shows that budgets and forecasts do not fulfil their anticipated accurateness • A production planner said: “How can we talk about schedules and plans given that only 10% of released production order come as intended?”
There is excessive levels of expediting (**UDE #2**)	• Stock levels do not correspond to actual demand • Self-constructed MPS is not able to deliver stable figures • Sales performance is measured partly on order intake, which often does not consider available capacity • “We are paid for taking orders in the field. This is a tough job, so production people should do their job!” one sales region manager clarified his view.
There are frequent shortages of raw materials (**UDE #3**)	• Demand for intermediate products is calculated manually based on the released production orders • Established min/max-style configurations for standard materials are not dynamically adjusted • Since production order fulfilment is weak in presence of permanent changes, their accuracy is questionable • Resulting demand for raw and packaging materials is often made on guesses or experience • “What else can we do? Production permanently changes the schedule and we are the last to know.” A procurement manager mentioned.

Production plans have a very limited life (**UDE #4**)	• Fluctuating and not foreseeable demand for finished goods requires expediting • Availability of intermediates and raw materials frequently demands for improvisation and immediate changes of original plans • Quality problems occasionally demand for unexpected re-work that further requires postponing of scheduled orders
Production lead-times are too long (**UDE #5**)	• Performance measurement favours local efficiencies over demand-orientated behaviour • Expediting interrupts production orders by the need to fit in small batches related to urgent customer orders • Inadequate stock buffers (too high or too low) require many small batches to be produced. Resulting cleaning and setup occupies existing machinery longer than needed. • The result is lead-times of some weeks that almost eliminate any flexibility. • "Tell me, how and when we should think about optimal production sizes and schedules? As you see, we are fire fighting here every minute and every hour!" one production manager explained his situation.
There is chaos (**UDE #6**)	• Demand is often not foreseeable • Priorities are unclear with the exception that customer orders should be shipped whatever it might cost • Current tools (e.g. MRP and individual solutions) do not address the requirements • Performance measurement is inadequate • Expediting has become the standard mode of operation • Complaints from sales, logistics and higher management address symptoms only • "The situation for us is easy: everything we can ever do is wrong at least for somebody in the company." the head of production planning summarised his situation.

Table 17 – Case UDEs with examples connected to theory

Having now identified the main issues InkCo is facing in form of the UDEs listed above, one has to notice that they are quite close to the generic production-related UDEs available from Cohen (2003) and many others as Harmony (2014). Their likely logical connections in form of cause and effect relationships should be discussed next. Before looking at the resulting CRT shown in Figure 30 the justified UDEs from Table 17 are shown together with causal links in the following Figure 29.

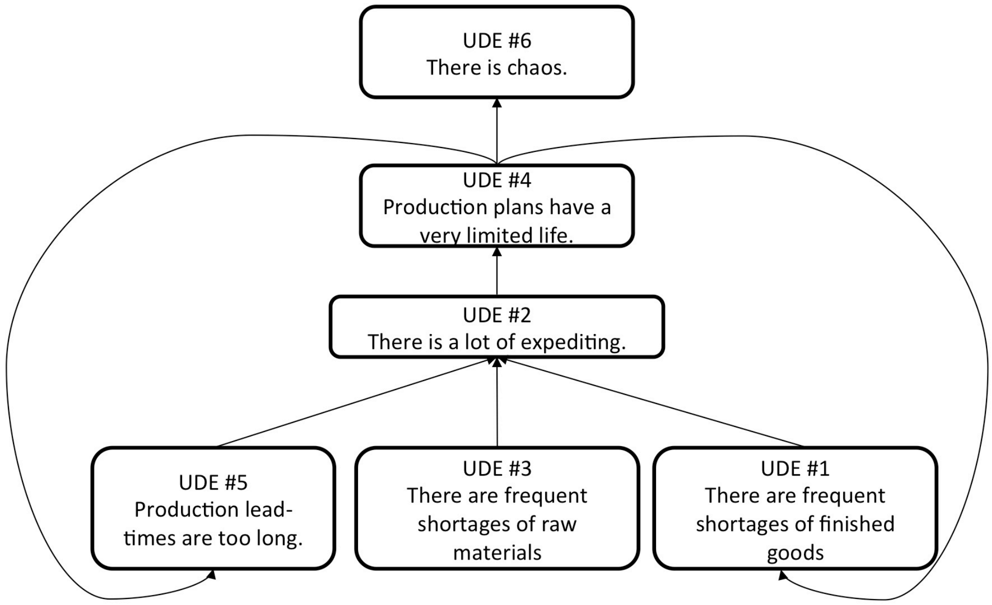

Figure 29 – UDE map

While the first five UDEs should follow easily from the case description provided, the last UDE 6 seems to be quite broadly or even colloquially worded. However, chaos is used as a synonym here for the combined disadvantages resulting from unacceptable inventory performance (e.g. too much of the wrong product and too little of the right product), unacceptable service level performance (e.g. low DDP) and high expedite related expenses and waste (e.g. additional freight charges and overtime). The map has been produced by using the case UDEs explained in Table 17 and been verified for correctness by colleagues at InkCo. The logical connections shown in the map are now described in turn:

UDE #5 ➔ UDE #2

Lead-times are quite long caused by things including unnecessarily large lot sizes and raw and intermediate material availability issues. Therefore, urgent orders need to be rushed through the production to satisfy customer demand. Furthermore, re-stocking orders sometimes need to be brought forward because original plans might cause stock outs before replenishment.

UDE #3 ➔ UDE #2

Unavailability of raw and packaging materials as well as of intermediate products for many reasons (e.g. inadequate safety stocks, quality problems, unreliable suppliers, "stealing away" issues) causes production orders to be postponed until availability of all BOM items is factual. At this time order for the resulting finished products are often overdue, which requires expediting activities.

UDE #1 ➔ UDE #2

Inadequately configured stock parameters, unanticipated demand, quality issues or unavailability of material (could justify a further causal link UDE #3 ➔ UDE #1) cause frequent shortages of finished goods. The result is the described permanent "fire-fighting" mode, which uses expediting to fulfil as many customer needs as possible in the current system.

UDE #2 ➔ UDE #4

Production plans are fixed every Thursday for the week ahead to be able to calculate the demand for intermediates and to provide procurement with products and quantities to be ordered. Prevailing expediting activities cause such plans to have only a limited validity period, which causes oscillating priorities and resulting changes.

UDE #4 ➔ UDE #5

Almost ever-changing production plans with work orders being fit into the originally planed ones cause some orders being late and postponed. This sometimes predetermines the production schedule for weeks ahead. The result is adding up on overall lead-time.

UDE #4 ➔ UDE #1

Production plans are made to satisfy current demand and fill up stock buffers to protect availability for the future. Changes to such plans in form of cancelled or reduced orders endanger availability and finally cause shortages and stock outs.

UDE #4 ➔ UDE #6

It now becomes evident that limited availability of plans cause by expediting and unforeseeable demand makes life difficult for the planning function. The description of "chaos" has been used influenced by statements made during the interview.

It has already been identified that a significant degree of similarity between generic UDEs and the one identified in the case study could be established. However, it is not only this congruence but also the similarity of logical connections that is close to the generic examples. However, the following Figure 30 shows a current reality tree that depicts these UDEs together with assumptions and neutral effects in order to fully describe the current reality at InkCo. It is therefore specific to InkCo although similarities to generic trees need to be acknowledged.

Mathias Ihme
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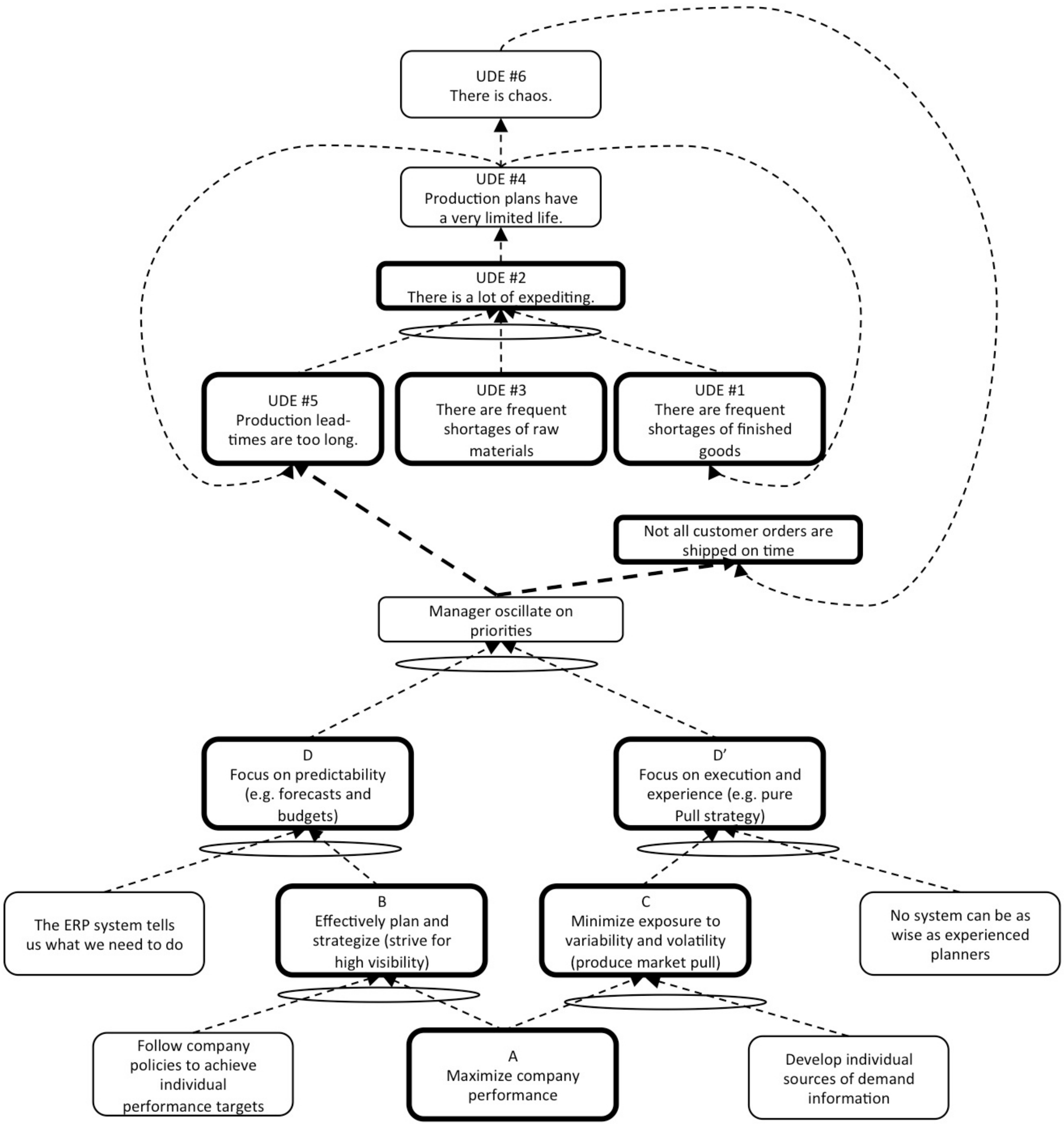

Figure 30 – Current reality tree

The CRT shows that the conflict mentioned in Chapter 2 (see Figure 9, p. 65) representing the common dilemma in today's MRP implementations is part of the current situation of InkCo. Furthermore, the UDE map shown previously in Figure 29 is also integrated in the diagram. Other boxes have been added to show further facts or conditions being relevant to the current reality.

Special focus needs to be spent on the element connecting the MRP conflict cloud (Figure 9) and the UDE map (Figure 29), being the oscillating priorities mangers are facing. On one hand, the planning function has to use the annual sales budget to prepare their MPS because there is no other information available. On the other hand, urgent orders and inadequate forecasts demand for a more demand driven planning. Since no clear rule exists in the current system explaining which realm to follow, managers try to do what they feel is best in every specific situation given. It seems that the planning team is so deeply involved into problem solving that they do not see a viable way out of their dilemma. The results identified in the figure in form of long lead-times and undesirable due-date performance are obviously true.

The hereby shown similarity or match of the current situation at InkCo with generic situations in production environments taken from the TOC literature and in MRP settings taken from the DDMRP literature justifies the assumption that the case fits with generic findings. Therefore, a certain degree of similarity and consistency is expected to be found throughout the rest of this document.

4.6 Areas for improvement

The previous section concluded with the current reality tree describing the current situation and likely causes and effects. It becomes clear that today managers at InkCo believe that a complex system like MRP does not have the potential to deliver results that are satisfying for maintaining adequate production planning and control results. Main reasons for this include MRP nervousness especially for intermediate materials and raw materials triggered by fluctuating and changing levels of demand. However, InkCo believes that budgets and sales forecasts are a valid instrument for steering the business and insists on their annual creation and on-going maintenance. This conflicting situation is the reason for using MRP only for finished products. However, the resulting need to create work orders for lower levels of the BOM manually while also having to plan available capacity on a manual basis causes an overall instability of the whole operational planning system that can be proven by the fact that only 10% of the work orders for finished products are completed as planned in terms of due dates and quantities. In absence of coordinated solution development, many self-made tools have been created that are more or less loosely coupled with the current ERP. Results in form of high stock levels on one side and stock outs on the other are at least questionable. The resulting core conflict is derived from the CRT and has been already identified as matching the generic one from the DDMRP literature (see Figure 9, p. 65).

However, it could not be stated that InkCo’s management is not willing to incorporate proper systems into their standard procedures. Moreover, the wish to establish more IT functionality that provides standardised procedures and reliable sources of information has been mentioned various times. Especially, the need to see, plan, synchronise and manage availability of all materials and components in an effective way has been stated.

Figure 31 shows two main strands that are intended to maintain and improve InkCo's performance. First, focussing on predictability and stability by relying on forecasts and well-adjusted stock configurations favours full MRP usage. Results in form of wrong stock levels (too high or too low) caused by misleading forecasts errors, nervousness by MRP's exploding of the entire BOM that disturbed the stability of the production function, lacking prioritisation functionality that clearly states what has to come first and various stock management attributes (lacking early warning, priority conflicts between MTO and stock replenishment) have caused InkCo to reduce the MRP functionality down to finished goods planning. On the other side, the established compromises in form of the large set of manual tools without proper interfaces to or from the ERP and a tendency to move from MTS although appropriate towards MTO style production planning have provided InkCo with the understanding that this is also not capable of delivering the performance levels in mind. The shear amount of finished goods together with demand variability and customers expecting quite tough lead-times in relation to the limited amount of warehouse space and machineries available makes MTO almost impossible.

Since both sides of the dilemma (e.g. pure push MRP and pure pull planning) have some right in their opposing perspectives and there is no realistic chance to move InkCo out of its obligations and resulting market and product requirements, a more innovative solution needs to be sought in order to break the cloud. An attempt to develop one major and two minor injections should help to justify a solution shown in form of a future reality tree in the next Figure 31. Such injections or actions are intended to solve the root cause or dilemma shown in the CRT and by this are able to turn UDE into desirable effects (DEs).

Injection 1

The core conflict between plan-focussed behaviour that prefers pure MRP application and the demand-focussed way that neglects plans in favour of pure demand consideration results from the previous sections. However, the theory chapter shows that the DDMRP methodology provides a systematisation that uses MRP as an integral part of an overarching framework consisting of five distinct elements. It provides clear priorities resulting from buffer states for all relevant materials. Furthermore, its component of strategic inventory positioning together with methods for determining inventory levels based on demand and variability have the potential to reduce lead-times significantly. The evidence from the literature is seen here as sufficient justification. However, the next chapter is intended to assess the improvement potential from a more practice-oriented viewpoint by undertaking a simulation. It should be seen as a deliberate attempt to test the potential value of DDMRP in a real life scenario.

Injection 2

Performance measurement of departments or even individual employees is common to manufacturing companies. However, performance measurement needs to be directed towards measuring the right things. Therefore, getting rid of local efficiency based performance targets and moving towards DDP oriented targets is sought.

Injection 3

Recent information about actual demand (i.e. customer orders) and future changes to demand patterns (e.g. seasonality, new products or sales promotions) is crucially important for achieving high levels of due date performance. Procedures addressing this need should be implemented instead of individual ways of information sourcing.

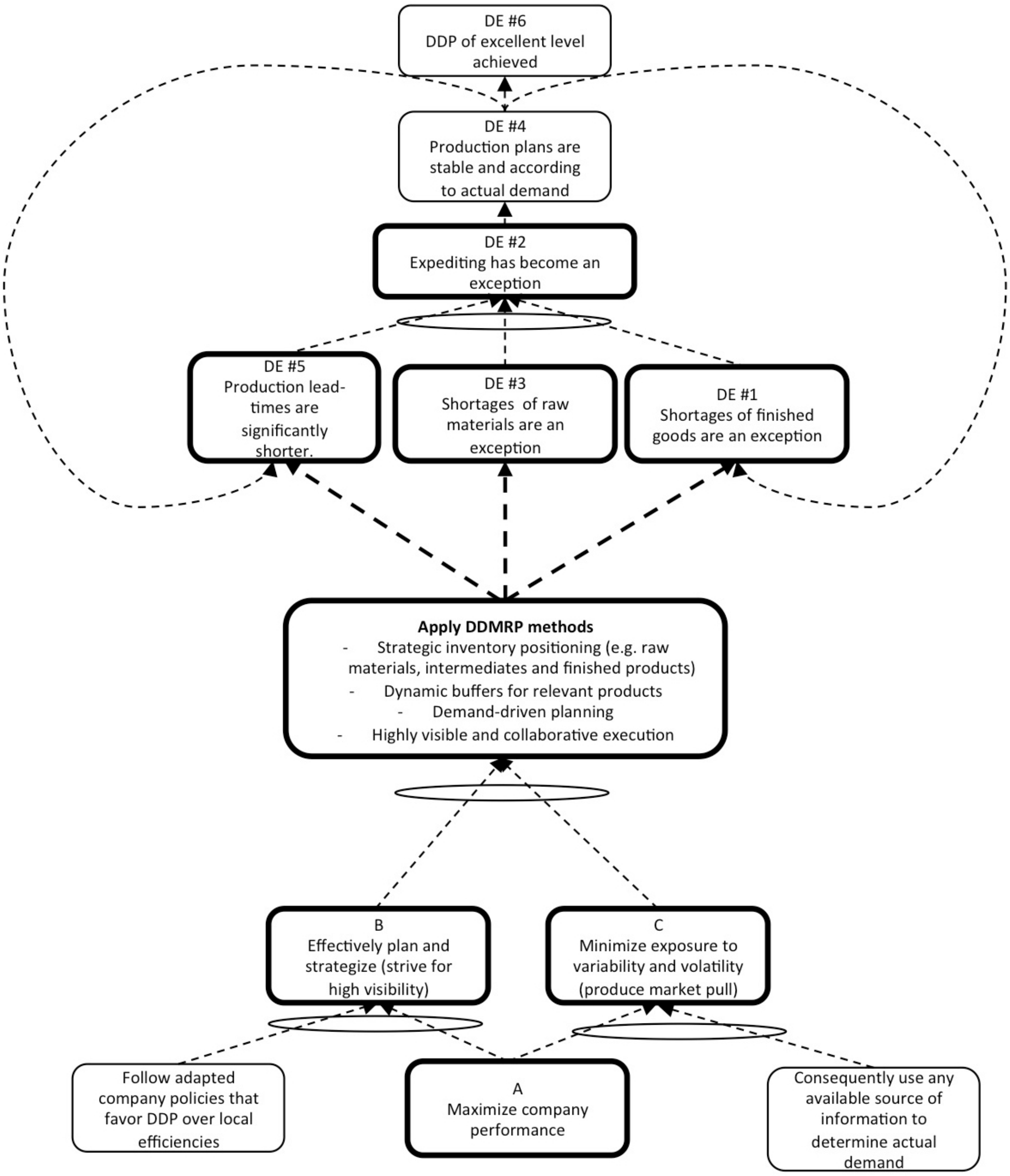

Figure 31 – Future reality tree

Although a deeper discussion of the findings is provided in a later chapter of this document, the FRT shows that the introduction of DDMRP methodology has the potential to turn UDEs into DEs based on logical sense making. A comparison of the individual elements of the CRT and the FRT might be helpful to develop a better understanding of the changes made and the resulting effects.

4.7 Implementing a new way of production planning and control

The previous sections of this chapter have described the current situation at InkCo and have tried to develop a strategy for improving the operational results. The new systhematization provided by DDMRP needs to be explained to all people involved including subject matter experts on the shop floor, production and planning managers and directors responsible for the production function. However, such an explanation that is intended to enable decision-makers to give their approval should be based on facts rather than pure theory. Therefore, the next chapter presents the results of a simulation that contains these facts in form of average stock and changes to the availability of SKUs.

Once people are convinced that the new way of performing production planning and control is worthwhile being implemented at InkCo, the real work starts. The simulation starts with the determination of buffer profiles and levels. This has already been done for a characteristic subset of SKUs by using existing databases and SQL scripts. These can be easily used for the remaining rest of the product range. However, having defined buffer profiles and having determined appropriate levels is only one prerequisite for implementing DDMRP.

The review of the literature and the following simulation stress the importance of strategic inventory positioning as another component of DDMRP. Such stock buffers help to decouple parts of the full production flow from others in order to improve flow and to shrink overall lead-time. Based on the understanding of InkCo gained through the course of work done for this research, raw and packaging materials as well as finished goods have been selected to become actively synchronised replenishment buffers. The following Figure 32 shows them in form of bucket icons within the whole transformation chain.

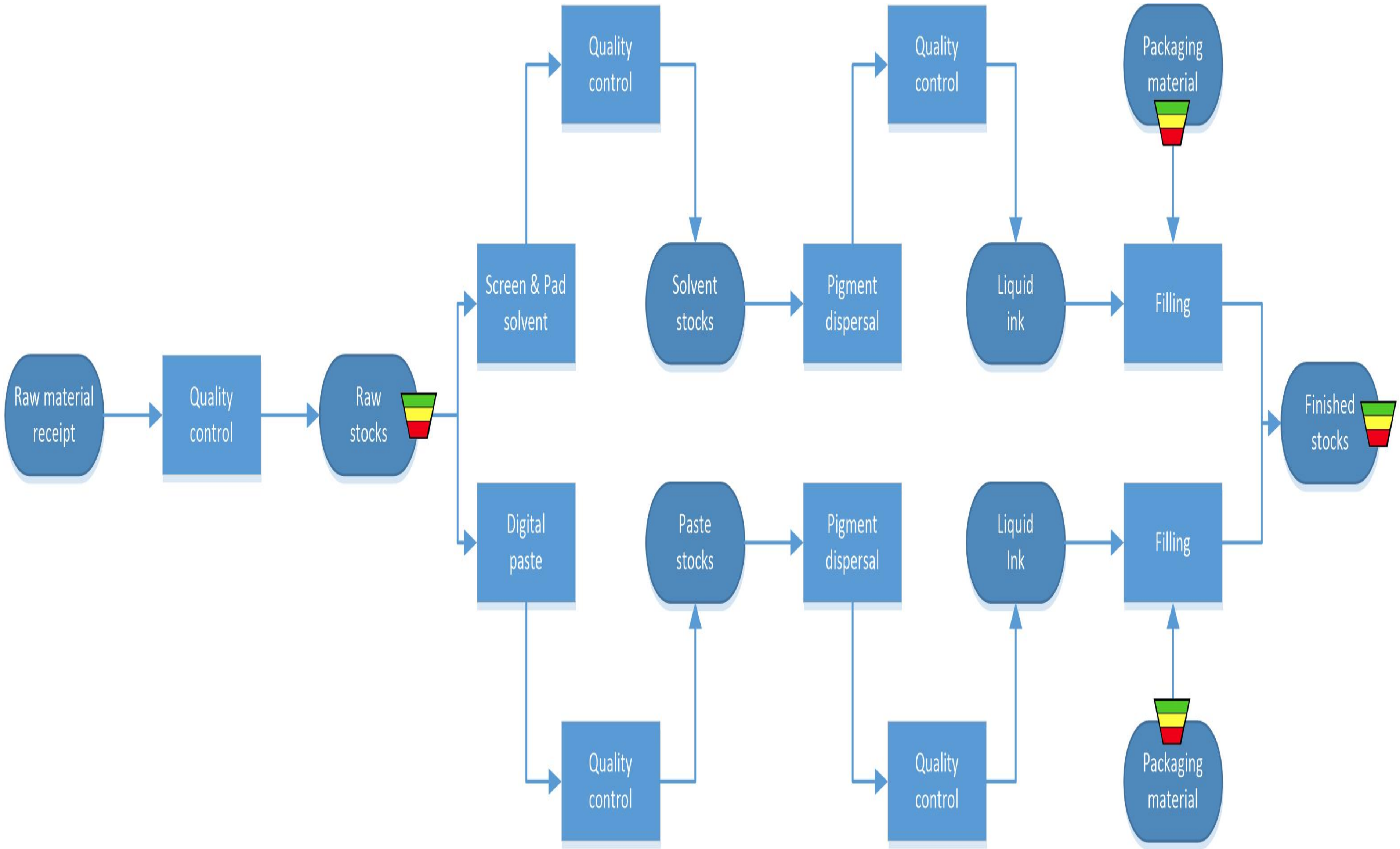

Figure 32 – InkCo system with inventory buffers

The later simulation has addressed the remaining components of dynamic buffers, demand-driven planning and highly visible and collaborative execution by using Excel® as the tool for data storage and transaction processing. This was possible only because the simulation dealt with a small subset of the full range of products and the simulation happened in isolation of the busy and sometimes ambiguous reality of the shop floor. It is almost obvious that one cannot forego the benefits from a fully integrated system that contains important information from the relevant areas of procurement, production, quality inspection, logistics and sales. Therefore, software is needed that represents the central tool for daily production planning and control.

Since InkCo has recently started a project that has the goal of evaluating the ERP market in order to find a replacement for the current ERP system, support for DDMRP ideas has been integrated into the catalogue of requirements. However, the results are far away from being satisfying since none of the market leaders (e.g. IFS, Infor M3, Microsoft Dynamics AX or SAP) offers DDMRP functionality as part of their standard. The remaining options include the integration of software that has been explicitly developed to provide DDMRP functionality (e.g. Replenishment+®) or to develop DDMRP functionality in the context of an ERP system as a large modification.

It has already mentioned that implementation is not the main focus of this research. However, this section provides the current state at InkCo and is intended to act as a linkage to a likely implementation stage in the future. Further ideas like recurring buffer recalculations and the introduction of control points, time and capacity buffers into the manufacturing system shown in the previous Figure 32 need to remain open tasks at this point in time.

4.8 Conclusions

The case analysis has started with a thorough description and analysis of the current supply chain implementation at InkCo. Special focus was set to the role of budgets and their relationship to the identification of demand. All this leads to a system of production planning and control that can be characterised as being in a permanent expediting and improvising mode (i.e. only 10% of work orders are completed as intended). The analysis concludes with a current reality tree that puts undesirable effects of the current ways of working in a logical cause and effect relationship. This has perfectly addressed the information needs of research question one to be answered in a later chapter.

In an attempt to find solutions for improving results, the core cloud resulting from the CRT is analysed. Three injections were found that are capable of breaking the cloud. The main finding is that DDMRP has the potential to turn UDEs into desirable effects. Furthermore, visibility in form of organised information capturing procedures needs to be improved. Finally, internal performance measurement focuses mainly on local efficiencies today and therefore hinders demand-driven behaviour. Changes of current practices are obviously required. The resulting future reality tree depicts the findings made.

Altogether, the situation at InkCo almost perfectly fits with the assumptions made in the generic clouds and trees used. Therefore, it can be stated that ideas from the world of TOC and especially DDMRP might have the potential to improve the overall situation. The next chapter is intended to provide more evidence for this claim by using real numbers for a simulation.

By identifying DDMRP as a potential methodology that helps to improve the current performance levels at the case company, the ground for answering research question two has been prepared. However, the evidence for its fit to the case company’s situation has only been justified on a theoretical basis. The practice oriented simulation is expected to deliver more concrete information being useful for later evaluation.

5 Simulation

5.1 Introduction

After having discovered that DDMRP might be a suitable method for turning the undesirable effects of the current situation into desirable effects once being implemented, more detailed facts about its potential are sought. Some information was already given in the last chapter that identified necessary steps for the implementation. Important is the part of winning 'hearts and minds', which means that an ideal implementation requires people that do not feel that the changed is imposed. This chapter is intended to provide the material that has the potential to convince people at InkCo not only on a theoretical basis, but also with facts about the performance of the new model. The simulation activity is perfectly suitable for this purpose.

5.2 Performance of the new model

The manager responsible for production planning was asked to identify a set of products that cover the variety of the whole product range in terms of including all product types and also the different sales profiles from fast moving over average until slow moving products. The full sample is shown in Appendix 10 of this document. To this sample the DDMRP methodology was applied by first determining buffer profiles and sizes. Data used to perform this task was extracted from the ERP system of InkCo to be as realistic as possible. The production manager supported this by coining that "our own figures cannot lie". The resulting buffer levels together with the calculation are shown in Appendix 11. After having determined the buffers, 2013 data was used to run a simulation that basis production related decision-making solely on buffer status. The simulation model and related decision-making rules are explained in Appendix 12. The results for the 28 products being part of this simulation are shown in Appendix 13 of this document. One might claim that this simulation is not fully representative because the future sales were known to the researcher. However, in order to address this possible weakness, sales visibility of only two weeks in the future was strictly maintained, which is a common feature of InkCo's real life situation.

Therefore, the simulation uses the buffer level determination and dynamic buffers adjustment element of DDMRP. Since DDMRP provides clear rules for making decisions solely triggered by demand in form of buffer status, the DDMRP component of demand-driven planning comes obviously into play. However, a major component in form of strategic inventory positioning could not be considered in an adequate way. The reason for this decision is that the sample of 28 SKUs is relatively small given a total of 5,200 SKUs representing the full product range. The likely effects of the much larger amounts of raw materials and intermediate products on inventory buffers and the resulting optimal locations could not be anticipated. Nevertheless, the presentation of the results provides indicators where inventory buffers might be helpful based on the information available. Furthermore, the DDMRP component of highly visible and collaborative execution could not be simulated adequately given the small extent of SKUs included. Although the alerting part is used to determine the effects, the competition for resources being the reality in InkCo's operations with urgent orders, material shortages and machinery breakdowns and their effect on decision-making could not be simulated. Therefore, the simulation assumes for decision-making that the production orders could be completed on time as required.

The full results are shown in the following Table 18 overleaf. Before interpreting the results, a detailed analysis of a sample of five SKUs is provided to demonstrate the process as well as the potential of improvement. During the analysis, some comments about features of DDMRP being outside of the scope of this simulation activity (e.g. strategic inventory positioning or buffer adjustments) are made to provide a fuller picture.

SKU	Litre	High inventory alerts		Low inventory alerts		Stock out alerts		Avg. stock (l)		Stock difference	Inv. red.
		Real	Sim	Real	Sim	Real	Sim	Real	Sim		
ADSP1	1	17	24	46	39	0	0	2130.00	2181.00	51,00	0
ADSP2	1	58	32	19	59	5	0	2354.00	1691.00	-663,00	1
ADSP3	1	54	30	21	18	3	0	952.00	833.00	-119,00	1
ADSP4	5	63	36	31	17	1	0	835.00	735.00	-100,00	1
ADSP5	1	0	7	21	8	1	0	2133.00	3554.00	1421,00	0
ADSP6	1	0	4	7	6	4	2	23.00	32.00	9,00	0
ADSP7	1	0	4	2	2	2	2	34.00	58.00	24,00	0
ADSP8	1	0	3	14	4	8	0	14.00	40.00	26,00	0
ADSP9	1	2	10	14	4	0	0	339.00	460.00	121,00	0
ADSP10	0.8	51	6	14	35	0	0	712.00	592.00	-120,00	1
ADSP11	1	60	42	11	13	0	0	4261.00	3391.00	-870,00	1
DDDP1	1	0	1	9	4	7	0	128.00	168.00	40,00	0
DDDP2	1	0	10	4	4	0	0	126.00	154.00	28,00	0
DDDP3	1	0	0	12	0	0	0	56.00	112.00	56,00	0
DDDP4	1	0	1	6	1	4	1	18.00	76.00	58,00	0
DDDP5	1	13	6	4	4	3	0	35.00	16.00	-19,00	1
DDDP6	1	15	5	2	3	2	0	54.00	17.00	-37,00	1
DDDP7	1	14	4	1	2	1	0	60.00	15.00	-45,00	1
DDDP8	0.44	0	0	109	13	32	0	66.00	232.76	166,76	0
DDDP9	0.44	0	14	93	21	17	0	61.60	131.56	69,96	0
DDDP10	1	0	4	7	1	1	0	86.00	116.00	30,00	0
ADSP12	5	21	23	26	6	12	0	635.00	830.00	195,00	0
ADSP13	5	24	0	23	16	0	0	740.00	615.00	-125,00	1
ADPP1	1	7	15	23	6	5	1	63.00	82.00	19,00	0
ADPP2	1	0	4	44	2	20	0	45.00	108.00	63,00	0
ADPP3	1	11	4	0	1	0	0	116.00	106.00	-10,00	1
ADPP4	1	0	8	14	1	1	1	42.00	75.00	33,00	0
ADPP5	1	181	42	3	30	0	0	1511.00	852.00	-659,00	1

43% less HI alerts	**45% less LI alerts**	**95% less stock outs**	**39% of SKUs reduced, 2% less in total**

Table 18 – DDMRP simulation results

ADSP2 1l

This product is a black all-purpose screen printing ink. It is well established in the market and therefore sold on a regular basis. InkCo has it categorized as a standard product being part of the A category of fast moving SKUs. Its lead-time falls into the long category of more than one month, because raw material in form of pigments has a significant lead-time from placing the order until goods receipt. Furthermore, relatively large batches often result in pigments suppliers shipping more than one pigment batch. This requires more time for quality control activities. Table 19 summarizes the facts.

Sales category	Ø batch size	Min batch size	Max batch size	LT category	ADU	Variability category
standard A	979	918	1041	long	73	low

Table 19 – ADSP2 facts

The DDMRP buffer determination resulted in an overall buffer size of 3,688 liter divided into 3,034 liter TOY, 851 liter TOR and 196 liter red safety. Figure 33 shows the application of the buffer zones to the real stock levels of 2013. One sees that unnecessary high stock levels did occur as well as stock outs towards the end of the year. Furthermore, production and batch size decisions do not seem to follow a specific scheme. The performance criteria shown in Table 20 provide the same picture with significant amounts of alerts.

Reasons for this unfavourable stock history were identified by production planning management including local efficiencies (i.e. larger batches to save setups and cleaning) in cases of high stock levels and lacking visibility of upcoming demand in cases of low levels.

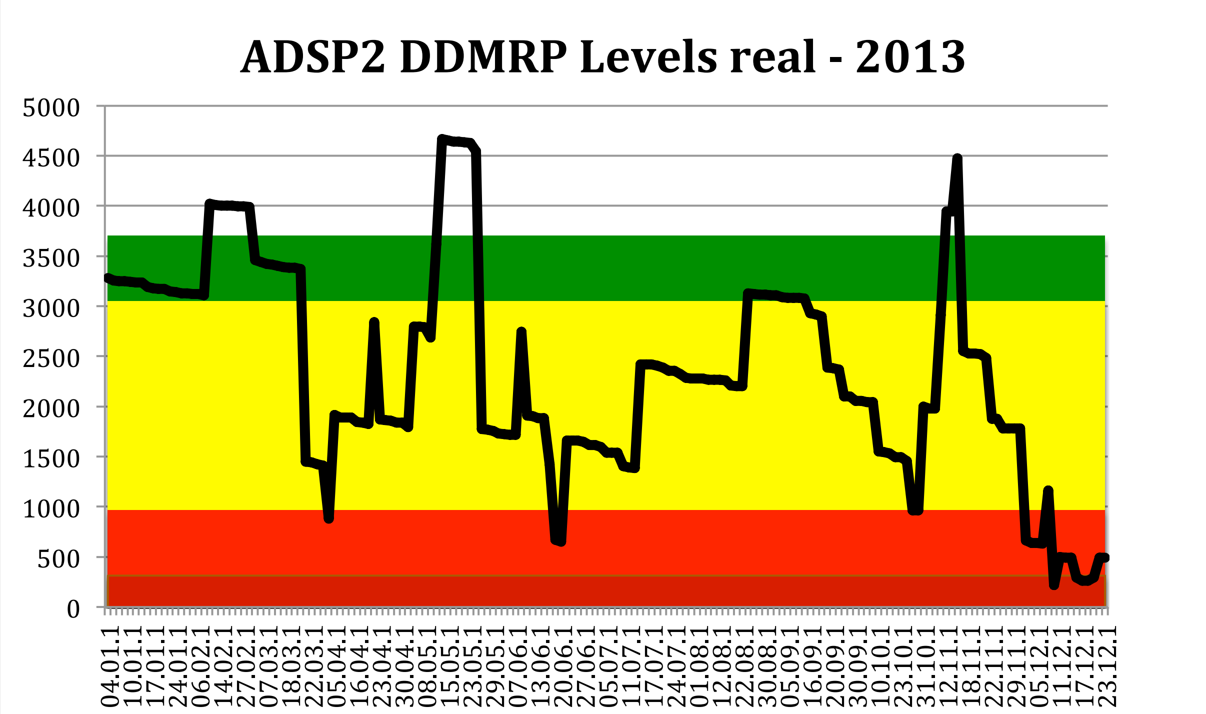

Figure 33 – ADSP2 stock levels and DDMRP buffers

The simulation was based on some rules of thumb including production decisions in the middle of the red base buffer, batch sizes to reach the green buffer or better to reach its middle and demand visibility of roughly ten days. The resulting stock levels shown in the next Figure 34 provide a different picture than the real stock levels shown in the previous figure. The decision-making rules bring standardisation into production decisions that are solely based on buffer status and upcoming demand in form of customer orders. It was always possible to follow the DDMRP systematic during the simulation.

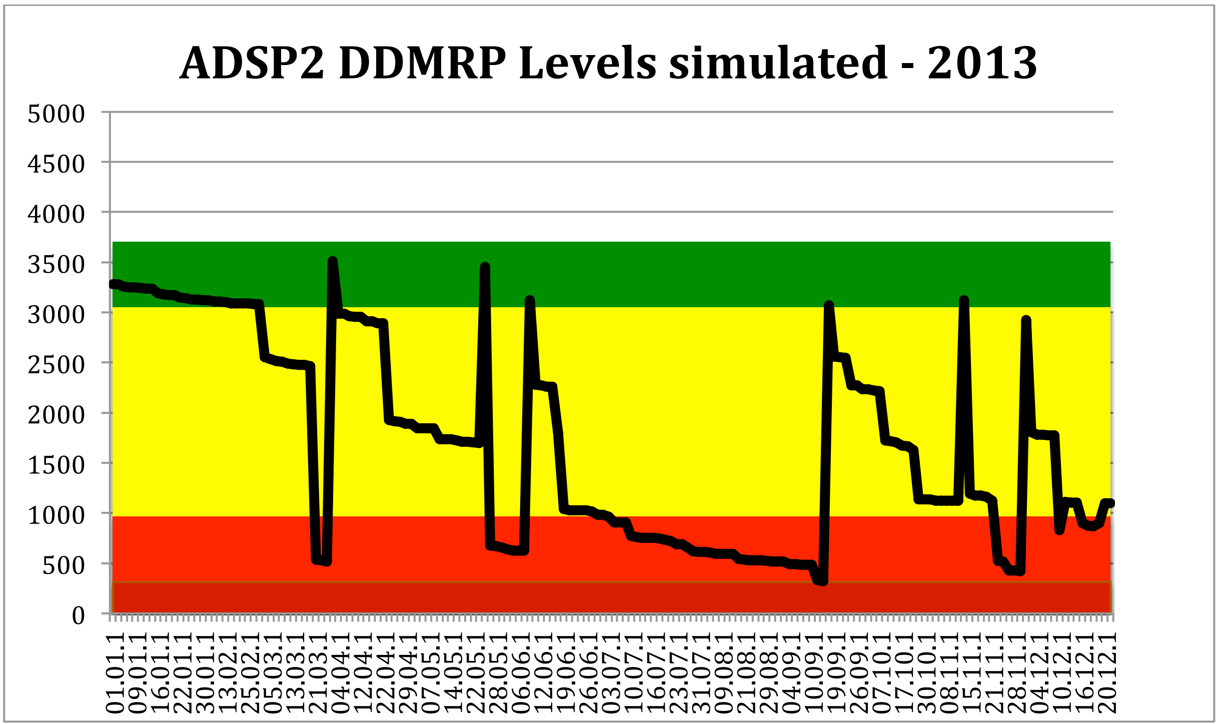

Figure 34 – ADSP2 DDMRP simulation

In an attempt of assessing the results, one can clearly identify the reduced amount of high inventory alerts, which are expected to have a financial benefit to InkCo in form of reduced capital invested in the warehouse. Furthermore, the simulation was able to avoid the stock outs towards the end of the year by triggering production decision earlier than in reality. However, the number of low inventory alerts has risen to about three times the amount than in reality. A reason for this is the rule of letting inventory levels fall down to the middle of base red before scheduling a production. Especially the long red period during summer time has caused many of such alerts. This period is also characterised by lower than average sales and sometimes longer lead-times on the supplier side caused by obvious events like holidays. Finally, the average stock level could be lowered by impressing 28% while having availability significantly improved. This means that DDMRP has helped to improve availability while being able to lower costs in parallel. The following Table 20 summarises the results.

Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	180	58	19	5	2354
Simulation	180	32	59	0	1691

Table 20 – ADSP2 DDMRP simulation results

Following the positive results achieved during simulation, some final thoughts should be made focusing on further improvement potential. The real data from 2013 show an increase of the ADU of 26% towards 92. This would result in increased buffer zone sizes if nothing else changes too. However, addressing the long lead-time seems to be worthwhile for lowering the impact of this effect. It results from the supplier lead-time for black pigments that could not be changed significantly according to information from the purchasing department. DDMRP suggests strategic buffer positioning as a method for reducing the overall lead-time. Therefore, creating a buffer for the pigments would result in a lead-time falling into the medium or even into the short category, which allows for smaller batches being produced more frequently according to the then current buffer status. Although, results of this activity cannot be determined based on speculation, DDMRP provides simple techniques for consideration of change.

ADSP8 1l

This product is a royal blue screen printing ink that serves the needs of graphic and art printers. It is sold for a couple of years, but due to its special focus only in small quantities. InkCo has it categorized as a slow moving product being part of the C category of SKUs. Its lead-time falls into the medium category of more than two weeks but less than a month. Raw materials in form of pigments needed are always ordered once a concrete production run is planned, which usually takes from a few days until almost two weeks. Due to the fact that low volumes are sold on a not always regular basis, the variability needs to be judged as high. Table 21 summarizes the facts.

Sales category	Ø batch size	Min batch size	Max batch size	LT category	ADU	Variability category
slow C	25	25	25	medium	3	high

Table 21 – ADSP8 facts

The DDMRP buffer determination resulted in an overall buffer size of 68 liter divided into 54 liter TOY, 26 liter TOR and 11 liter red safety. Figure 35 shows the application of the buffer zones to the real stock levels of 2013. It is observable that stock levels were too low throughout the year. Furthermore, production and batch size decisions do not seem to follow a specific scheme. Thus, production orders were released only after stock out situations occurred. The performance criteria shown in Table 22 provide the same picture with significant amounts of low stock and stock out alerts.

The sole reason for this unfavourable stock history was identified by production planning management in form of the unpredictability of demand. The need to produce this ink became visible after stock out situations only. The wish to have a stock monitoring tool that is able to warn planners of the optimal stock level and of upcoming stock outs was articulated.

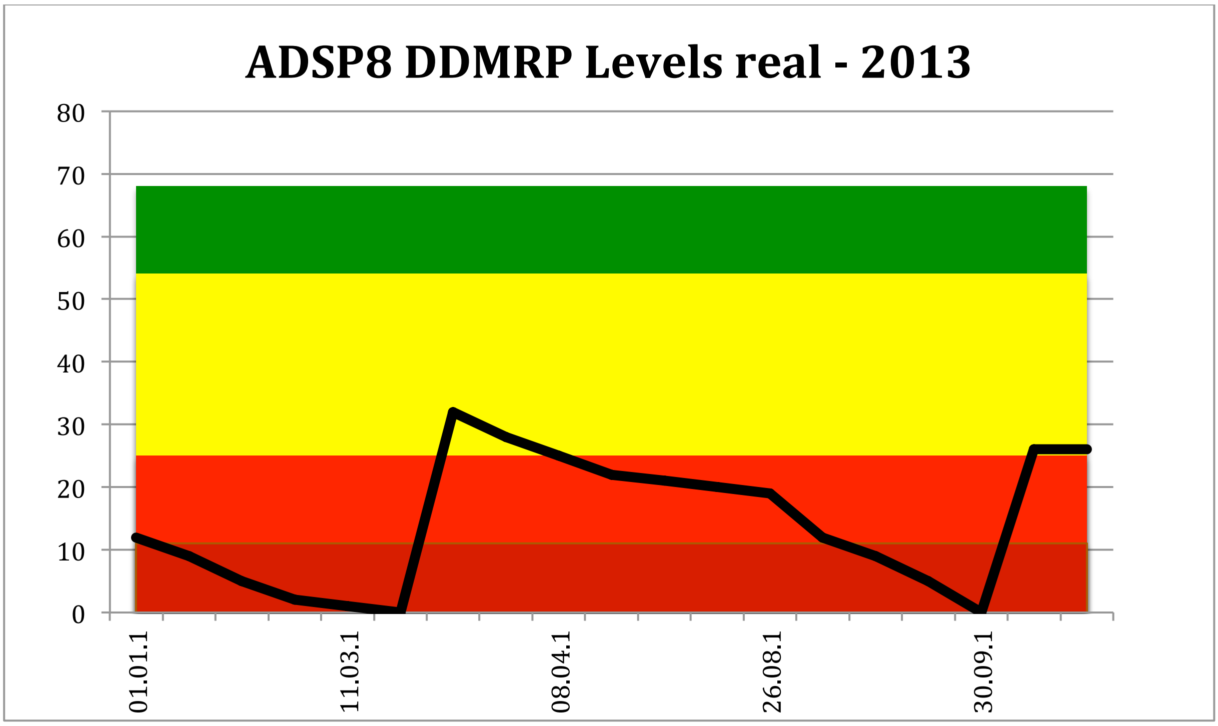

Figure 35 – ADSP8 stock levels and DDMRP buffers

The simulation was based on some rules of thumb already stated for the first SKU. The resulting stock levels shown in the next Figure 36 provide a different picture than the real stock levels shown in the previous figure. The decision-making rules bring standardisation into production decisions that are solely based on buffer status and upcoming demand in form of customer orders. It was always possible to follow the DDMRP systematic during the simulation. Honestly, this was easy because the resulting stock from the initially justified production run lasted longer than the simulation horizon of one year.

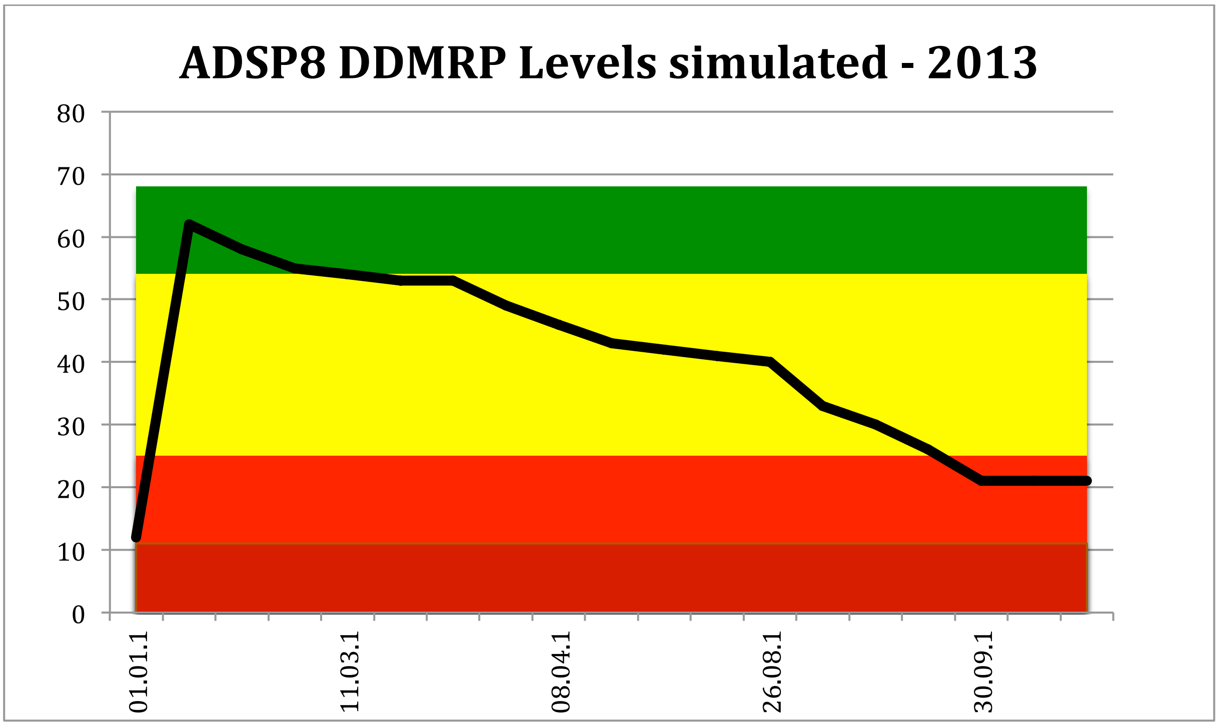

Figure 36 – ADSP8 DDMRP simulation

The results of the simulation clearly show an increased amount of high inventory alerts, which are not expected to have a significant financial benefit to InkCo due to the very small quantities involved. Furthermore, the simulation was able to avoid the stock outs throughout the year by triggering production decision early in the year that fills up the buffer. The number of low inventory alerts have also fallen down to 29% of its original quantity. The main reason for this seems to be a mismatch between the buffer sizes calculated and the one actually needed. This is further supported by the fact that the average stock level was increased to more than three times the value resulting from reality. Although increased availability often has a price, the relationship at least triggers some further questions. Overall, DDMRP has helped to improve availability and provided clear rules for decision-making. The following Table 22 summarises the results.

Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	21	0	14	8	14
Simulation	21	3	4	0	40

Table 22 – ADSP8 DDMRP simulation results

The simulation results demand for some further interpretation as well as for thoughts leading to further improvement. It was possible to avoid any stock outs by increasing the average stock level significantly. Having this result in mind while viewing the stock levels shown in Figure 36 induces the question if the calculated buffer sizes fit the characteristics of the product. A first comparison of the ADU of approximately 3 in 2012 and 3.5 in 2013 does not really support the need for recalculation. Moreover, the lead-time category has been chosen according to real parameters that might be optimized by introducing strategic inventory positioning. If this makes sense for a low volume product it needs to be further investigated in the context of all SKUs produced. However, the variability class of high that requires setting red zone safety to 80% of the red zone base value seems to be inadequately set. The graph shows slow but also steady sales that might be able to justify lowering the variability down to medium or even further down to low. The resulting effect of decreasing average stock by roughly 18% seems not to be of any importance due to the low quantities involved. However, the principle of adjusting buffer sizes to changed circumstances becomes clear. Overall, the results for this product show that availability has a price in form of inventory being held. The only viable way of reducing this burden is to switch this product from MTS over to an MTO style. Production managers have criticized this idea because producing low quantities of only a few liters would not justify the resulting setup and cleaning activities. Although this is understandable by the author further information resulting from consideration of the full product range need to be taken into account.

DDDP5 1l

This new product is an opaque white digital all-purpose printing ink that is UV curable. It has been introduced to the public in 2012 as being available for delivery at the beginning of 2013. Marketing has therefore made a forecast that expects only small quantities being sold. InkCo has it categorized as a slow moving product being part of the C category of SKUs. Its lead-time falls into the medium category of more than two weeks but less than a month. Raw materials in form of pigments needed are always ordered once a concrete production run is planned, which usually takes from a few days until almost two weeks. Due to the fact that low volumes are expected to be sold on a not always regular basis, the variability needs to be judged as high. Table 23 summarizes the facts overleaf.

Sales category	Ø batch size	Min batch size	Max batch size	LT category	ADU	Variability category
new C	0	0	0	medium	1	high

Table 23 – DDDP5 facts

The DDMRP buffer determination resulted in an overall buffer size of 24 liter divided into 19 liter TOY, 9 liter TOR and 4 liter red safety. Figure 37 shows the application of the buffer zones to the real stock levels of 2013. It is observable that stock levels were more often far too low throughout the year. However, beside massive overstocking even stock outs have occurred. Furthermore, production and batch size decisions seem to follow a specific scheme. Thus, production orders were released after stock levels of 5 litre. The size of the orders is presumable not influenced by actual demand. The performance criteria shown in Table 24 provide the same picture with significant amounts of high stock and stock out alerts.

It is often difficult to anticipate the demand for new products that do not have a sales history. Therefore, marketing forecasts need to replace history to determine the ADU. Furthermore, lacking experience of producing this product influenced the batch size to be similar to well-established products of the same family (i.e. 30 to 40 litres). The third production having twice this size was triggered by sales expectations that were not realised. The need to base production decisions rather on actual demand than on sales forecasts was mentioned by production planners during the simulation.

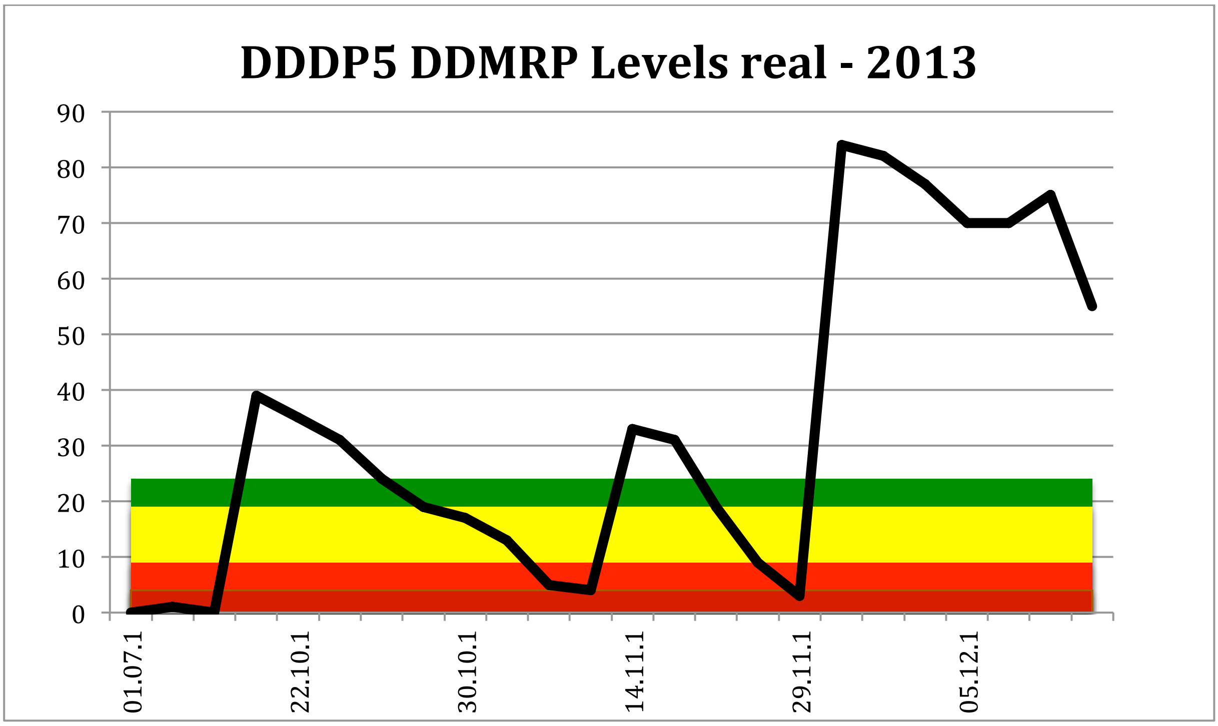

Figure 37 – DDDP5 stock levels and DDMRP buffers

The simulation was based on some rules of thumb already stated for the first SKU. The resulting stock levels shown in the next Figure 38 provide a different picture than the real stock levels shown in the previous figure. The decision-making rules bring standardisation into production decisions that are solely based on buffer status and upcoming demand in form of customer orders. It was always possible to follow the DDMRP systematic during the simulation. However, the high demand variability required production batches of different sizes coming in variable frequencies. In a few cases, production orders seem to be too large in comparison with the real demand. Reasons for this are order cancellations having happened after the production order was released to the shop floor.

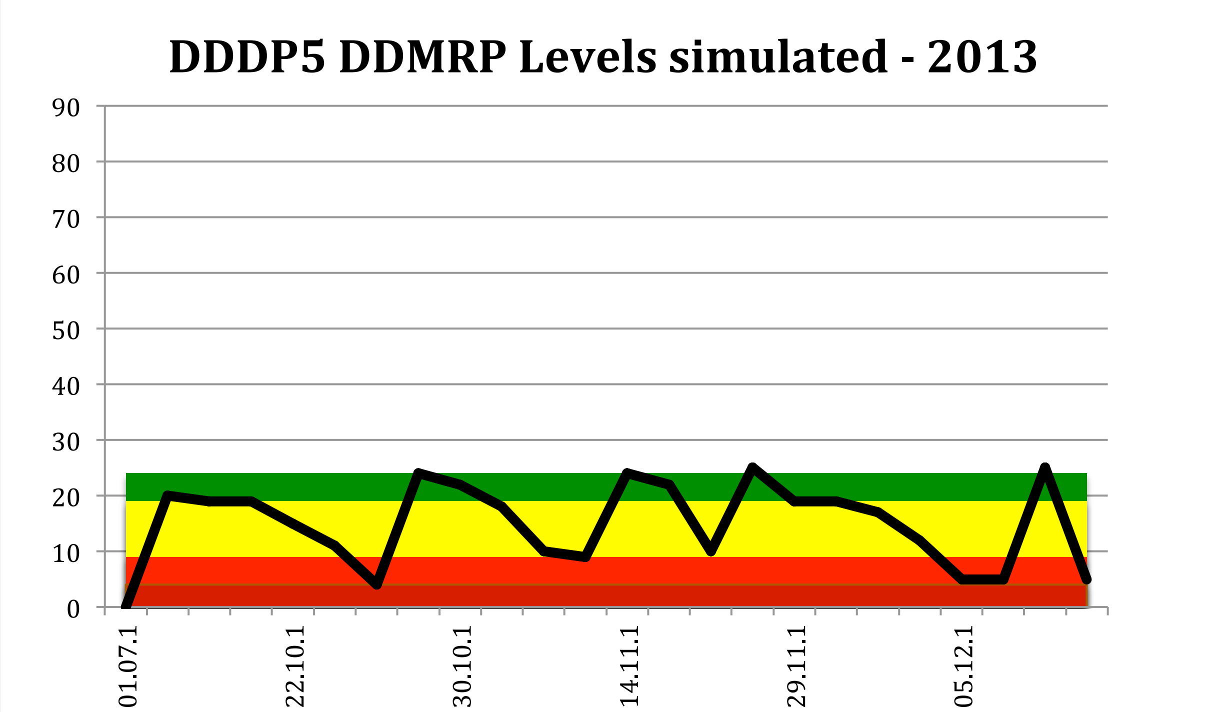

Figure 38 – DDDP5 DDMRP simulation

The results of the simulation show only 50% of the high stock alerts that happened in the reality of 2013. Unfortunately, this reduction of stock that is also visible from the average stock figures shown in the next Table 24 cannot deliver significant financial benefits, because the quantities involved are quite small. Furthermore, the simulation was able to avoid the stock outs throughout the year by triggering production decision early in the year that fills up the buffer initially. The number of low inventory alerts stays the same since production decision rules allowed for letting the stock fall deep into the red zone. This might be seen as increasing the risk of stock outs on one side but on the other side it reduces overall stock and represents a certain variability caused the many more products being produced in reality. Finally, the number of stock outs were reduced down to zero, mainly caused by the initial production decision at the beginning of the year. Overall, DDMRP has helped to improve availability while also reducing stock levels by approximately 50%. It provided clear rules for decision-making solely based on actual demand. The following Table 24 summarises the results.

Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	26	13	4	3	35
Simulation	26	6	4	0	16

Table 24 – DDDP5 DDMRP simulation results

The simulation results demand for some further interpretation as well as for thoughts leading to further improvement. It was possible to avoid any stock outs while also decreasing the average stock level significantly down to 50% of its original value. However, the ADU underlying the buffer determination was 1 according to the marketing assumptions, which is in stark conflict with the ADU in the reality of 2013 of 16. A consequent buffer recalculation based on the changed ADU would have resulted in increased average stock on one side but unchanged benefits on the other. This supports the finding made for the last SKU that availability comes at a price. Moreover, increased buffer sizes resulting from consequent application of the DDMRP rules are intended to protect this availability. The simulation cannot consider concurring priorities resulting from many SKUs being in their red zone. More buffer available means more flexibility while still being able to ship. Even when buffer sizes are calculated based on obviously wrong assumptions; the performance of the DDMRP method is impressive. Production managers have reported their excitement about the results. Being able to see decision-making solely based on demand even for unknown product behaviors that delivers excellent results in terms of availability and stock size is key to future success, as one of the managers stated.

DDDP8 440ml

This product is a mainstream yellow digital all-purpose printing ink that is solvent-based. It is sold to the market for a couple of years and is known for its good results on many different printing machines. InkCo has it categorized as a standard product being part of the B category of SKUs. Its lead-time falls into the medium category of more than two weeks but less than a month. Raw materials in form of pigments needed are in stock to a varying extent or ordered once a concrete production run is planned, which usually takes from a few days until almost two weeks. The product is sold internationally having customers in most of the countries InkCo serves. One might expect reduced variability resulting from this diversification. However, globally fluctuating demand requires setting the variability category to medium. Table 25 summarizes the facts.

Sales category	Ø batch size	Min batch size	Max batch size	LT category	ADU	Variability category
standard B	214	199	229	medium	40	medium

Table 25 – DDDP8 facts

The DDMRP buffer determination resulted in an overall buffer size of 1,023 440ml cartridges divided into 796 cartridges TOY, 341 cartridges TOR and 114 cartridges red safety. Figure 39 shows the application of the buffer zones to the real stock levels of 2013. It is observable that stock levels were almost always too low throughout the year. It seems that production orders have only been released only when stock out situation have happened. The size of the resulting batches was never high enough to stabilize the situation since stock levels have never escaped the red zone. This is supported by performance results shown in Table 26. Here one can find almost dramatic amounts of low stock and stock out alerts.

Production planners have identified the main reason for this situation as being the wish to reduce the stock level. Since this product has a shelf life of only one year, they see this behaviour as negative for availability but as necessary for avoiding waste. Therefore, some allowance for stock outs was part of decision-making rules. Nevertheless, the wish to have a stock monitoring tool that is able to inform planners of the optimal stock level and warn them of upcoming stock outs was articulated.

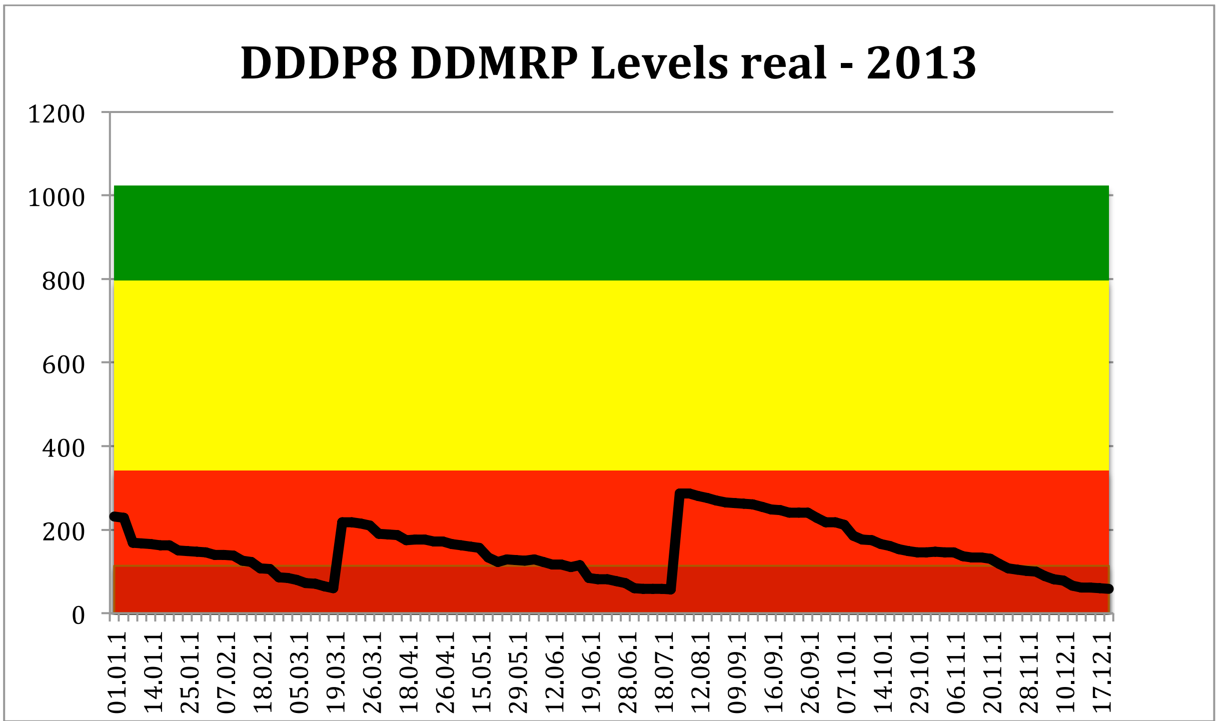

Figure 39 – DDDP8 stock levels and DDMRP buffers

The simulation was based on some rules of thumb already stated for the previous SKUs. The resulting stock levels shown in the next Figure 40 provide a totally different picture than the real stock levels shown in the previous figure. The decision-making rules bring standardisation into production decisions that are solely based on buffer status and upcoming demand in form of customer orders. It was always possible to follow the DDMRP systematic during the simulation. The deep red buffer status at the beginning of the year required an initial production run that filled up the buffer. A steady flow of sales orders reduced it almost constantly down to red zone at the end of the year.

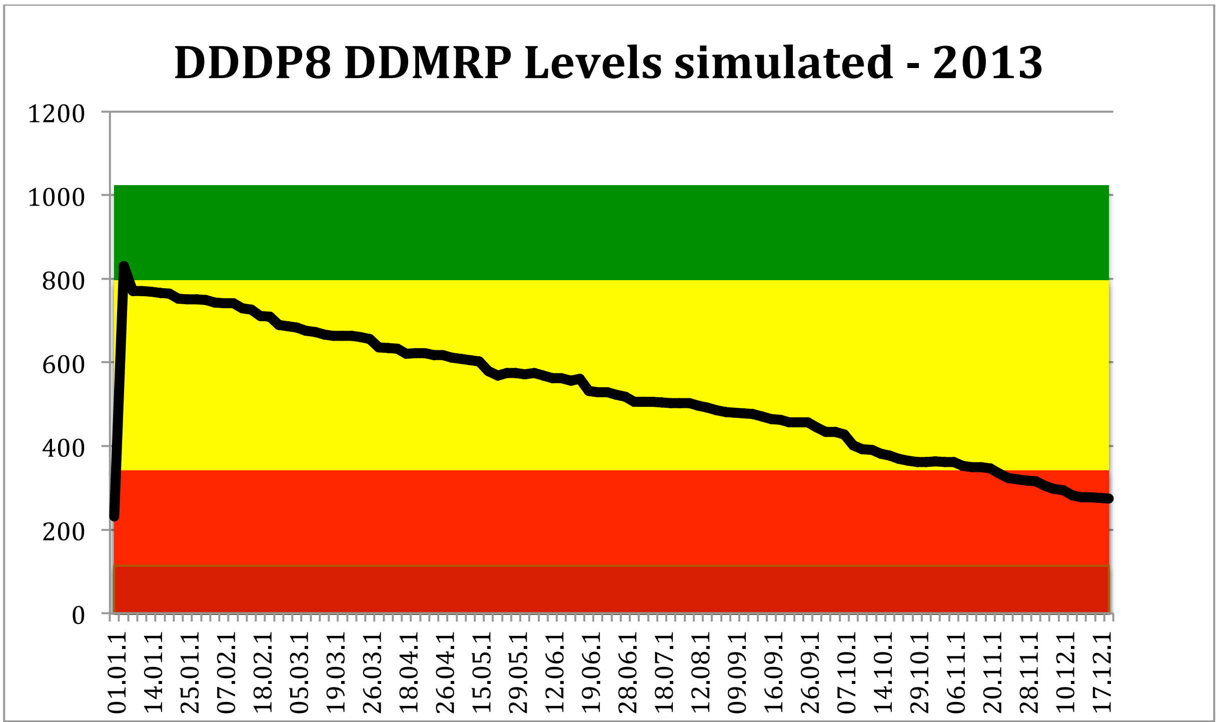

Figure 40 – DDDP8 DDMRP simulation

The simulation was able to avoid any stock outs throughout the year by triggering a production decision early in the year that fills up the buffer. The number of low inventory alerts also fallen down to 12% of its original quantity. The main reason for this seems to be a mismatch between the buffer sizes calculated and the one actually needed. This is further supported by the fact that the average stock level was increased to more than three times the value resulting from reality. Although increased availability often has a price, the relationship at least triggers some further questions. Overall, DDMRP has helped to improve availability and provided clear rules for decision-making. The following Table 26 summarises the results overleaf.

Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	112	0	109	32	150
Simulation	112	0	13	0	529

Table 26 – DDDP8 DDMRP simulation results

The simulation results demand for some further interpretation as well as for thoughts leading to further improvement. It was possible to avoid any stock outs by increasing the average stock level significantly. Having this result in mind while viewing the stock levels shown in Figure 40 induces the question if the calculated buffer sizes fit the characteristics of the product. A first comparison of the ADU of approximately 30 in 2012 and 12 in 2013 provides strong support for the need for recalculation. The resulting effect of a recalculation based on the ADU of 2013 would allow for decreasing the average stock by roughly 50%. This might nullify the negative effect of increased stock shown in the simulation while still being able to maintain the beneficial availability results. Overall, DDMRP methods show their potential for improvement by providing clear rules for decision-making. Furthermore, their demand-driven nature provides sureness and comfort to production planners.

ADPP5 1kg

This final product is a black pad printing ink that is designed for industrial applications. It is sold to the market for many years and is known for its good results on many different printing machines. InkCo has it categorized as a standard product being part of the B category of SKUs. Its lead-time falls into the medium category of more than two weeks but less than a month. Raw materials in form of pigments needed are in stock to a varying extent or ordered once a concrete production run is planned, which usually takes from a few days until almost two weeks. The product is sold internationally having customers in most industrialized countries InkCo serves. The demand over the last years and especially in 2012 is steady and constant over the year. Table 27 summarizes the facts.

Sales category	Ø batch size	Min batch size	Max batch size	LT category	ADU	Variability category
standard B	360	355	363	medium	37	low

Table 27 – ADPP5 facts

The DDMRP buffer determination resulted in an overall buffer size of 1,606 kilograms divided into 1,232 kilograms TOY, 485 kilograms TOR and 112 kilograms red safety. Figure 41 shows the application of the buffer zones to the real stock levels of 2013. It is observable that stock levels were almost always too high throughout the year. It seems that production orders have not only been released justified by real demand but also to keep production machinery busy. This claim was supported by production planners who said “you can produce this ink whenever you have spare capacity as it will be sold anyway”. The size of the batches in 2013 reflects this statement. Figure 41 shows productions initiated at green or slightly yellow buffer states that have different sizes (i.e. corresponding to the free capacity available). This is supported by performance results shown in Table 28. Here one can find almost dramatic amounts of high stock alerts.

As already mentioned, production planners have identified the main reason for this situation as being the wish to avoid machinery staying idle. Since there is no real penalty for producing unnecessary stock while having performance criteria focussing on output, the behaviour is a logical consequence. Nevertheless, as in most of the other cases the wish to have a stock monitoring tool that is able to inform planners of the optimal stock level and warn them of upcoming stock outs was articulated.

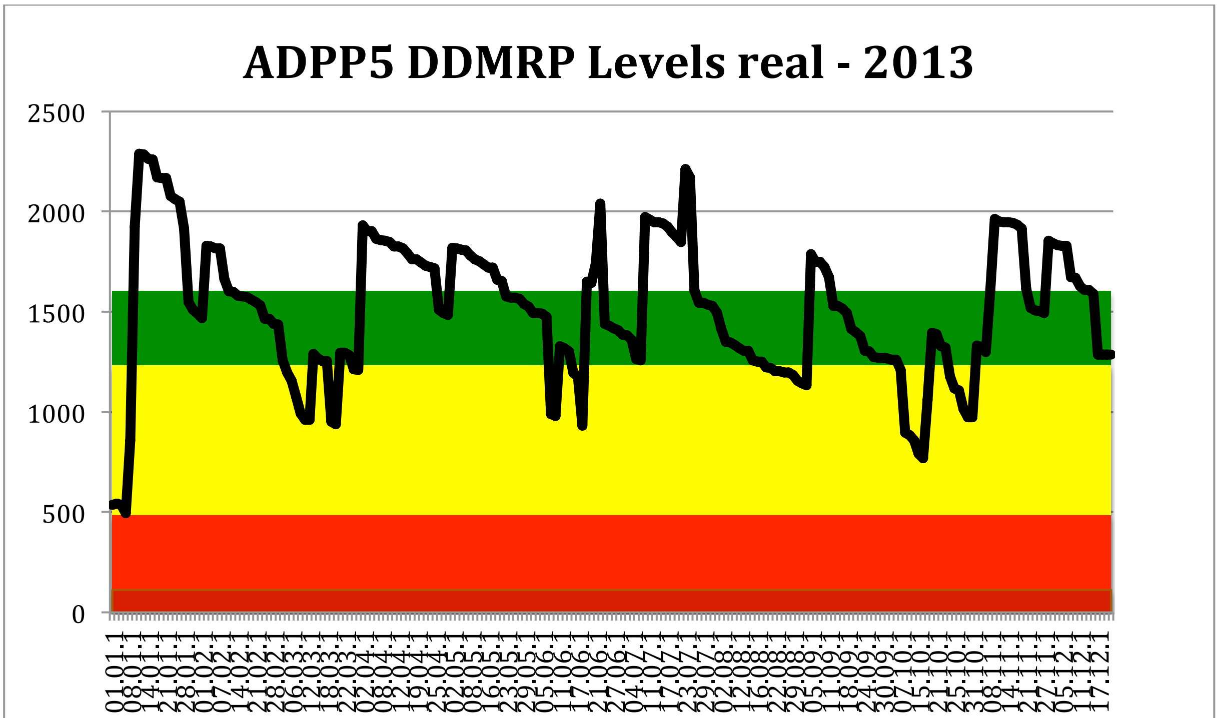

Figure 41 – ADPP5 stock levels and DDMRP buffers

The simulation was based on some rules of thumb already stated for the previous SKUs. The resulting stock levels shown in the next Figure 42 provide a totally different picture than the real stock levels shown in the previous figure. The decision-making rules bring standardisation into production decisions that are solely based on buffer status and upcoming demand in form of customer orders. It was always possible to follow the DDMRP systematic during the simulation.

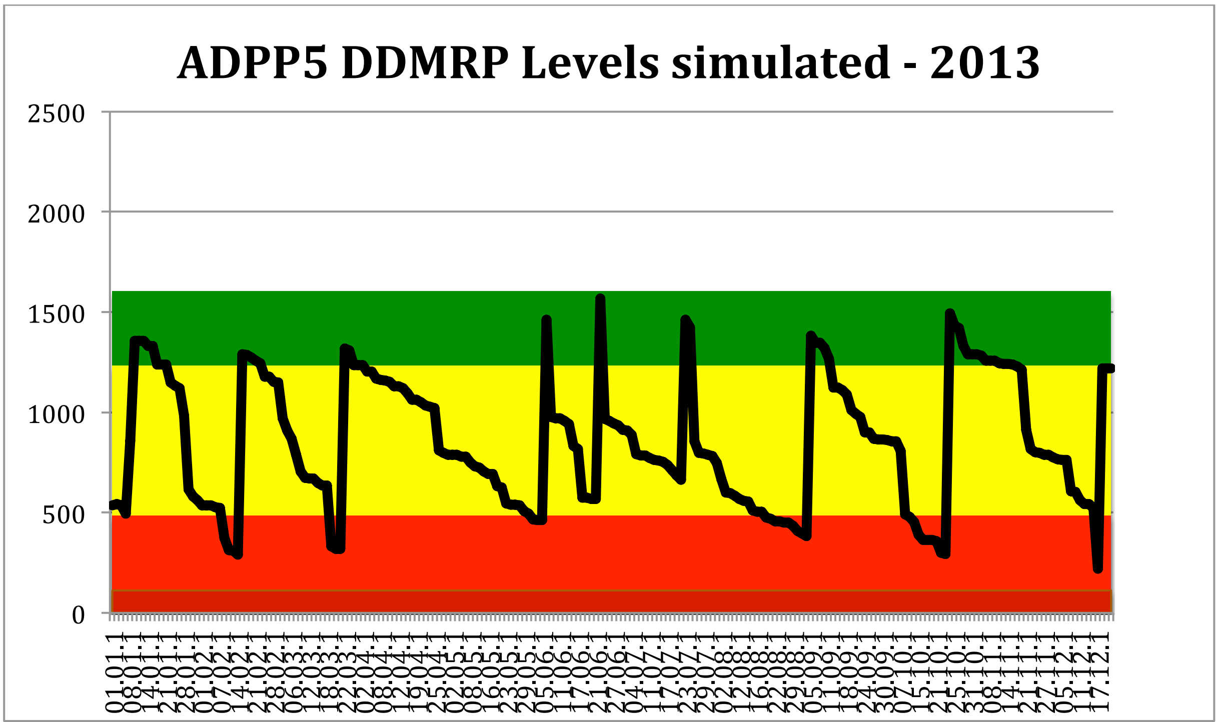

Figure 42 – ADPP5 DDMRP simulation

The simulation was able to avoid many of the high stock alerts and reduces them down to 23% of the original value. The number of low inventory alerts is ten times higher than in reality caused by the fact that the simulation allowed for letting the stock fall to the middle of red. The overall reduction of stock shown previously on the basis of the decreased count of high inventory alerts is further supported by the average stock level figure, which is only 56% of the real quantity. Availability could not be increased as it was already at a 100% value, but resulting cost in form of stock and its production could have been significantly reduced. DDMRP has helped to decrease costs while maintaining highest availability levels enabled by clear rules for decision-making. The following Table 28 summarises the results overleaf.

Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	226	181	3	0	1511
Simulation	226	42	30	0	852

Table 28 – ADPP5 DDMRP simulation results

The positive results of the simulation showed the possibility to reduce stock significantly while not jeopardizing availability in any way. Having the result in mind while viewing the stock levels shown in Figure 42 indicates that the buffer configuration is in harmony with the product demand profile. A comparison of the ADU of approximately 37 in 2012 and 38 in 2013 justifies the last assertion. Therefore, any form of buffer adjustment in 2013 seems not necessary. If one wishes to further improve the planning results for this product, lead-time seems the only available area. Here, improving the availability of the required raw materials by creating strategic stock buffers might be leading to a shrinked lead-time for the finished ink. As this should allow for adjusting the buffer DDMRP buffer levels downwards, further stock reduction might be possible that does not affect availability negatively. However, this slightly speculative conclusion needs to be verified in a real-life scenario that includes the full product range.

5.3 Simulation results

The last sections have provided illustrative examples of how DDMRP works and what potentials for improvement it might yield. The results should now be summarised to extract the main influence areas of DDMRP.

Availability

DDMRP techniques have the potential to improve product availability dramatically by first providing the decision makers with a clear and simple set of rules to be applied to the products in focus. All examples showed an increasing fit of the actual stock levels with the specific demand patterns of the products. Effects include reduction of high stock alerts in cases where the original stock levels were too high in relation to real demand. Further effects are distinct changes to the amount of low stock alerts in both directions. If stock levels originally were too high, an increased amount of low stock alerts is the likely consequence of DDMRP application. In the other case were stock levels were predominantly too low, a reduction of low stock alerts is a probable result. Finally, stock out situations are dramatically reduced if not even eliminated due to the decision-making rules and also caused by visibility of buffer states.

Stock

The increased availability discussed previously results in different effects on the level of stock. Sometimes the actual level of stock is simply too low for protecting availability. The determined buffer zones indicate optimal stock levels and trigger production orders being released and completed in order to build up stock. In these cases an increased stock level would be the consequence. However, the resulting cost can be justified easily as the price for availability. The other classic examples of too much stock could also be found among the examples. Here, DDMRP buffers are effective in reducing stock that might have been built up due to performance criteria requiring the exploitation of local efficiencies or due to the lack of demand visibility. In all cases stock needs to be seen as a protective measure for availability. Other kinds of stock have also mentioned in form of strategic inventory positioning. This means the decision to create stock for certain raw or intermediate materials in order to shrink the overall lead-time of the related finished product. This certainly comes at a cost, which hopefully could be justified by resulting reduced finished good buffers due to the shorter lead-times.

Structure

Both previous paragraphs have highlighted the influence of DDMRP methods on the key elements of availability and stock. It becomes clear that a certain structure has been created that determines distinct rules for planning and execution behaviour. First, demand becomes visible by showing it in conjunction with the resulting buffer states. Production managers at InkCo found it very easy to follow the related rules and understood the requirements of DDMRP almost intuitively. Decision-making became detached from past experience and sales forecasts in favour of consequent consideration of on hand stock and actual demand. Both criteria have been considered by production planners as hard facts that are part of their daily job. Second, justification for decisions being made can be easily derived from DDMRP buffers, whereas the traditional ways of working often demand for complicated and sophisticated argumentation. However, a likely conflict has also been uncovered in form of a mismatch between efficiency orientated performance measurement and DDMRP results. As a consequence, performance measurement needs to be changed towards focussing on due-date performance (availability) and adequate stock levels (possible cost reduction).

Limitations

The introduction to the last chapter has already identified that the relatively small amount of SKUs used in this simulation might reduce the generalizability of the findings made. While looking at the results from the reality of 2013, one might ask whether this was the maximum the current system can be produce. Although this research cannot answer the question in a reliable way, the case study offers at least some evidence that justifies some doubts (e.g. oscillating priorities, efficiency focussed measurement). Moreover, one needs to question the replicability of the simulation results in the real environment of 5,200 SKUs. The aforementioned conflicts and competition for resources might have a limiting effect. Furthermore, the simulation has shown the need for more production orders coming in smaller lot sizes compared to the results from reality. Neither the amount of production orders for all products and the respective lots sizes nor the feasibility on the production layout given can be anticipated here.

However, DDMRP has shown its ability to improve availability in an understandable way. If a full application of DDMRP techniques to InkCo's factory will uncover the need to invest in resources or inventory to improve availability then the resulting decision needs to be made informed by facts.

5.4 Conclusions

This chapter dealt with implementation and simulation of the DDMRP methodology. The simulation provided promising results in comparison with the reality of InkCo. Clear indications have been found that DDMRP has the potential to improve availability while also adjusting stock levels to real requirements. However, potentially limited validity of the findings might result from the small sample of SKUs.

Overall, DDMRP provides structure and simple rules helpfull for decision-making and prioritising. However, implementation seems to be an activity that is not as clear-cut as the simulation results. Current ERP systems do not offer DDMRP functionality as part of their standard, which makes the integration of third-party products or individual software development necessary.

Overall, the richness of information about the performance improvement potential of DDMRP is seen to be sufficient to be able to develop the answer to the second research question. Especially its practice focus delivering performance figures common to practitioners in the field of production planning and control determines the value of the findings.

6 Discussion

6.1 Introduction

This chapter presents the findings resulting from the single-case analysis in chapter 4 and the simulation activity in chapter 5. Although, Eisenhardt (1989) and Yin (2009) characterise case study research as a continuous process, results are shown as final due to the identified limitations of this research project. The chapter starts with an identification of the main findings established in the case study and the simulation. After this, the process of developing the answers to the two research questions is presented. A small section tries to determine the generalizability of the findings made.

6.2 General findings

The case study has provided an in-depth analysis of the case company. During this analysis, an attempt has been made to discover the degree of fit between generic UDEs and cause and effect relationships resulting from the TOC methodology and the actual situation at InkCo. An certain degree of fit could be justified, which made replacing current procedures and policies by DDMRP components a valid and also promising idea. The following simulation activity shown in the previous chapter has enhanced this finding by providing a clear understanding of the current situation as of 2013 and possible improvements resulting from DDMRP methodology. However, one need to be cautious while interpreting the results since the simulation had to accept past performance as a given fact. Although one cannot identify to what degree past performance could have been improved by better using or applying current ERP functionality, at least some doubts remain. As an example one could focus on the current ERP implementation, which involves finished goods requirements planning only. Interviewees have complained about having to calculate the demand for intermediate products manually, although the required functionality is available from the current system. Everybody seems to be fully occupied in a way that no attempt to introduce such planning for the full BOM has ever made before.

Nevertheless, the interplay between case findings, numerical representations and support from the literature provides the ground for developing answers to the two research questions, although specific improvement results need to be interpreted in a careful way. Especially, the relationship to specific UDEs allows for verification of the ideas developed in the previous two chapters. The following Table 29 shows this data combination overleaf.

UDE	Case findings	Further evidence	Literature support
There are frequent shortages of finished goods	• Supply of semi-finished products not stable (stealing) • Varying first-rate yield due to quality issues • Inadequate stock levels	591 high, 580 low and 129 stock out alerts	• Cohen (2010), Srikanth (2010) • Ehie and Sheu (2005)
There is excessive levels of expediting	• Sole focus on financial budgets makes real demand consideration difficult • Stock levels for finished goods not set according to actual demand	591 high, 580 low and 129 stock out alerts	• Goldratt and Cox (1984), Goldratt (1990) • Ptak and Smith (2011)
There are frequent shortages of raw materials	• Min/Max controlled stocks not updated regularly • Actual production demand not used to trigger orders (MRP linkage missing) • Supplier lead-times often too long to support frequent production plan changes • Cost-based performance criteria sometimes in conflict with demand • Delivered quality sometimes not according to specifications		• Plossl (1995) • Ptak and Smith (2011) • Ptak and Smith (2011), Sproull and Nelson (2012)
Production plans have a very limited life	• Manufacturing is not designed as supporting sales (lacking synchronisation) • Missing raw materials demand for plan changes to maintain high levels of utilisation • Lacking MRP usage for semi-finished products causes availability problems		• Hayes and Wheelwright (1985) • Goldratt and Cox (1984), Ptak and Smith (2011) • Ptak and Smith (2011)
Production lead-times are too long	• Focus on local efficiencies causes lot sizes too high • Supplier lead-times are not optimised towards availability	See SKU ADSP2	• Schragenheim et al. (2009) • Ptak and Smith (2011)
There is chaos	• Usage of self-developed tools that are not ERP-synchronised • MTO instead of MTS • Overall instability caused by decision-making based on incomplete information	8 Access DB, uncountable Excel spreadsheets	• Ptak and Smith (2008) • Cohen (2010) • Ptak and Smith (2011)

Table 29 – Summary of case findings in relation to UDEs and theory

Having now presented the findings, a more detailed discussion of four main improvement areas presented above should allow for evidence to support the facts found. The resulting deeper understanding of the situation and the reasons for its current shape might not only be useful for reconstructing the conclusions made but also for the development of answers to the research questions later.

Procurement

The procurement function is only loosely coupled with the MRP system and production planning in general. Stock levels for raw and packaging material are usually determined once a new material is created in the ERP system. These Min/Max values are only adjusted in cases of strong misalignment with the overall requirements. Seasonality or promotional activities are shared with procurement on a manual basis. After the weekly production-planning meeting, the production orders for finished products are used for determining the material demand on a manual basis (Excel). Purchase orders are then transmitted based on the assumption that the production plan for next week is fixed, although it is common understanding that the opposite is true. Reasons for this obviously inadequate behaviour include lacking functionality of the current ERP system but also local performance measurement criteria. Procurement's performance is judged against a budget derived from the annual sales budget. Surely it is not fair to say that people involved do not care about availability and responsiveness, but achieving their cost-based targets seems to be important too. Furthermore, known issues in the area of long supplier lead-times and quality are not addressed since most of the time is consumed by manual work.

The first couple of issues can be easily addressed by a full DDMRP implementation. Since demand-driven planning is at its core, buffer states for raw and packaging material are continuously updated driven by changing demand on the finished product side. Furthermore, strategic inventory buffers are monitored in a similar way. Both help to provide focus for things to do earlier than others. Purchasing activities are purely driven by real or upcoming demand that also provides procurement members with real quantities. Moreover, the dependence on the weekly production planning meeting and its results is almost eliminated since results of that meeting are known in advance in form of buffer projections into the future. Accordingly, purchasing activities are decoupled from planning decisions in a certain way. Regarding promotional activities or seasonality, a similar situation of independence is created, because such events are reflected well in advance by adjusted buffers. For purchasing it simply looks as increased demand shown in increased demand levels at the raw and packaging materials. The introduction of DDMRP tools should reduce manual work to such an extent that enough of time will be freed up useful for investing it into the real issues of lead-time and quality. However, performance criteria need to be shifted away from a pure cost focus towards supporting availability. Maybe something like internal DDP could be created that is better able to measure the performance of the procurement function.

Production and planning

The production function and its planning is today largely based on experience of production planners. Though MRP is used today its focus is solely set on planning finished goods requirements. However, the information MRP needs to end up with realistic and demand-orientated plans is not as good as it could be since the underlying MPS is determined manually from the financially orientated annual sales budget. Moreover, unanticipated demand in the form of rush orders or promotional activities that unearths mostly without prior notice trigger frequent changes to demand and plans. Therefore, the weekly production plan is only able to cover the actual demand roughly. Furthermore, the fact that the demand for semi-finished goods is planned manually by using various Excel spread sheets adds to the speculative character of the plan. Having now some form of weekly plan verified to be producible on the existing machinery and with the workers available, raw material availability comes into play. Problems in this area already mentioned in the previous paragraph require changes to the plan on a regular basis. Finally, performance measurement of the production function is largely efficiency orientated. This means that a tendency to create lot sizes larger than needed in order to minimize non-productive times of machineries and workers is visible.

DDMRP addresses the dependency of the actual planning activities on the MPS in an elegant way. Finished goods consumption is taken in form of the ADU figure to determine buffer sizes that are almost independent from sales budgets. Further information needed to develop suitable buffers in form of variability and lead-times can be taken easily from previous year's figures. However, buffer determination is only the starting point since frequent review of their suitability that could lead to recalculations is a crucially important activity. Decision-making that leads to production orders is then solely based on real demand visible in form of the buffer status of the finished goods. The resulting lot sizes are expected to follow DDMRP rules that ask for quantities not going over a certain defined level of the green buffer. Since this procedure is dynamic, the need for fixing the production schedule one week ahead is not existing anymore. Production decisions are expected to happen every day and result in a current lead-time figure that represents the load of the production function varying according to actual order intake volumes. Such production orders are then the basis for an MRP module to peg down the BOMs and to create production orders for semi-finished goods and purchase orders for raw and packaging materials. Furthermore, the creation of buffers for certain materials helps to protect the system from variability of supply. All this helps to create a production function that is supportive for maintaining high levels of DDP required by the business. However, current performance measurement criteria need to be shifted away from concentrating on local efficiencies towards measuring availability. DDP might act as a suitable measurement criterion.

Stocks

Stock levels for finished goods are determined today mainly based on individual experience of production planners and warehouse management. The common inadequacy of such stocks comes in both extremes. On one side stock outs are not an everyday issues but happen on a regular basis while on the other side overstocking becomes visible in form of monthly devaluations. Furthermore, warehouse capacity sometimes becomes a bottleneck when for instance packaging material in large quantities has been ordered based on rough demand estimates that often focus on reducing cost (i.e. better price for larger quantities or reducing the amount of shipments). It became obvious that lacking tools and policies for determining optimal stock levels and an overall system instability are root causes for the issues described.

The simulation has shown that DDMRP is able to provide the required procedures and policies for managing stock. Easy calculations of buffer sizes create the basis for the determination of optimal stock levels that are subject to monitoring and adjustment. The result is not a stock reduction in general but stock levels that help to protect availability and in the end DDP. This surely comes at a cost not only in the area of finished goods but also for intermediates and raw or packaging materials. The aforementioned strategic inventory positioning that establishes buffers to protect availability and to reduce lead-times needs to be paid for. However, being able to satisfy customers by shipping on time to a high degree should be able to outweigh the increased cost by far.

Availability

While carrying out the required work for the case study, no explicit proof that availability is managed in a structured way has been found. Examples that support this finding are easily obtainable from the previous paragraphs. They include the partial MRP usage and resulting stock outs or waiting times caused by unavailability of semi-finished goods or purchased materials, unnecessarily large lot sizes that prevent additional productions of required products by occupying resources too long or inadequate usage of buffers that limits the ability to ship on time on a frequent basis. Decision-making is surely orientated towards achieving high levels of availability but the lack of adequate tools and procedures on one side and local efficiency orientated performance measurement in many areas on the other side limit performance almost dramatically.

During the simulation, DDMRP has shown the ability to provide a structure for all production-related decision making. Buffer status becomes the sole criterion for the creation of production orders in sizes that are intended to support availability but not more than this. Regular monitoring and adjustment of buffers to be better able to reflect the current demand situation are helpful for becoming responsive to fluctuating market demands as well as to seasonality. Inventory buffers for purchased materials and semi-finished goods further help to maintain high levels of flow through the production, which at the end supports availability of finished goods. Furthermore, adequate lot sizes are expected to free up capacity that could act as another protection against variability by creating the ability to run more production orders in a defined period if needed. Finally, highly visible execution makes decision-making reliable, replicable and communicates demand down the BOM levels. All this helps to create a stable system of interconnected functions that is designed for achieving high levels of DDP.

Contrasting the current situation and resulting issues under the above four headings with possible improvements resulting from the DDMRP methodology could be seen as another prove of its beneficial character. Before moving to the answers to the two research questions, the following Table 30 is intended as a summary from which elements are woven into the following three subchapters.

DE	Findings	Further evidence	Literature support
Shortages of finished goods are an exception	• Adequate buffer levels consider demand, variability and lead-time • Dynamic buffers (frequent recalculation) • Often smaller lot sizes reduce resource occupation	339 high, 320 low and 7 stock out alerts See comments in chapter 5 See SKU DDDP5	• Schragenheim et al. (2009), Ptak and Smith (2011) • Ptak and Smith (2011) • Goldratt and Cox (1984), Sproull and Nelson (2012)
Expediting has become an exception	• Highly visible and replicable execution • Dynamic buffers adjust to varying demand • Direct consideration of open orders in form of on-hand stock • Clear rules for priorities	See SKUs in simulation See comments in chapter 5 See simulation rules in chapter	• Ptak and Smith (2011) • Ptak and Smith (2011) • Schragenheim et al. (2009), Ptak and Smith (2011) • Ptak and Smith (2011)
Shortages of raw materials are an exception	• Demand-driven planning • MRP connects demand for finished goods to demand for raw materials • Strategic inventory positioning	See simulation rules in chapter 5 See discussion in chapter 4 and 5	• Schragenheim et al. (2009), Ptak and Smith (2011) • Plossl (1995), Ptak and Smith (2011) • Srikanth (2010), Ptak and Smith (2011)
Production plans are stable and according to actual demand	• Adequate buffer levels • Highly visible and replicable execution • Demand-driven planning by direct consideration of open orders in form of on-hand stock	339 high, 320 low and 7 stock out alerts See SKUs in simulation	• Schragenheim et al. (2009), Ptak and Smith (2011) • Ptak and Smith (2011) • Schragenheim et al. (2009), Ptak and Smith (2011)
Production lead-times are significantly shorter	• Often smaller lot sizes • Strategic inventory positioning reduces exposure to stock-outs	See SKU DDDP5 See comments in chapter 5	• Goldratt and Cox (1984), Sproull and Nelson (2012) • Srikanth (2010), Ptak and Smith (2011)
DDP of excellent level achieved	• Clear rules for decision-making • Interconnectedness of all relevant functions • Reliable and supporting levels of stock absorb variability • High levels of availability due to dynamic buffers	See simulation results in chapter 5 Not only in theory (see chapter 2) See chapter 5 See SKU discussion in chapter 5	• Ptak and Smith (2011) • Ptak and Schragenheim (2004) • Srikanth (2010), Ptak and Smith (2011) • Schragenheim et al. (2009), Ptak and Smith (2011)

Table 30 – Summary of improvement opportunities in relation to DEs and theory

6.3 Major performance limiting issues

This subchapter is intended to develop the answer to the first research question asking **what the issues are in InkCo's current planning and control system that limit performance.** The previous section has put the UDEs in relation to case findings summarised in Table 29. This is intended as a starting point towards defining the targets of change, which are still seen as being connected to one or more specific UDEs. This understanding how it might be possible to convert them into the appreciable DEs is shown in Table 30. The following Table 31 presents the ideas, which are further discussed afterwards. Each UDE or group of UDEs is discussed and concluding remarks are presented in italics before moving to the next issue. Such remarks could be additionally seen as recommendations.

UDE	Change target	Comments
#1 There are frequent shortages of finished goods **#2** There is excessive levels of expediting	• Buffer sizing and management • Finished products stocks • First-rate yield for finished products • Inadequate planning of semi-finished goods • Strong focus on financial budgets and forecasts • Lacking procedures for establishing a proper MPS • Missing consideration of actual demand in production planning • Ignorance of current production load by sales	• Protection of the supply chain from process and supply variability • Appropriate stock levels in relation to lead-times and variability • Addressing of production quality issues • Lacking MRP support • Production planning happens in quantities of SKUs and not in currency units, forecasts are often not reliable • Establish sales oriented planning beside current revenue focused plans • Lack of synchronization between sales activities and demand recognition • Missing consideration of current production lead-times during delivery date determination
#3 There are frequent shortages of raw materials	• Buffer sizing and management • MRP implementation • Supply management	• Protection of the supply chain from external supply variability • Lacking consideration of actual demand • Addressing of lead-time and quality issues
#5 Production lead-times are too long	• Current performance measurement criteria • Supply management	• Replacing local efficiency focusing criteria by better suitable indicators • Evaluate current lot sizing practices • Addressing of lead-time and quality issues
#4 Production plans have a very limited life **#6** There is chaos	• Missing integration of relevant functions along the supply chain • Weak MRP implementation • Exit the vicious cycle	• Aforementioned lack of synchronization of existing sources of relevant information • Only partial usage requires various workarounds and manual tools • Address weak overall system stability and reliability

Table 31 – From UDEs to change targets

From the previous table it becomes easily visible that the UDEs one and two need to be seen in conjunction. Current stock levels for finished goods are mainly determined by work experience (see Table 29, 1st row) and not by systematic evaluation and consideration of market needs characterised by volume and demand variability and company-specific needs in form of lead-times. Moreover, the last point leads to issues caused by the current MRP implementation, which only focuses on finished products (see Table 29, 4th row). Demand for semi-finished products is calculated manually based on a weekly production schedules assumed to be fixed. Since the opposite is true, the calculated demands can only be correct by accident. Finally, the prerequisites for adequate production planning need to be verified to be existing. InkCo strongly believes in financial budgets and targets in form of forecasts that explicitly not contain any quantitative information in relation to SKUs or product groups (see Table 29, 2nd row). This deficit can be taken further down towards daily operations and the related lack of information sharing. Actual demand is mostly hidden until the point when sales orders are created into the ERP system (see Table 29, 4th row), which makes any form of preparation an impossible activity. However, this lack of information does not happen in one direction only since sales neither has access to current production lead-time information nor has ever asked for it. Permanent expediting consumes most of the available time (see Table 29, 2nd row), which makes detailed investigations into existing quality issues an almost impossible activity.

The way the organisation is grouped around a so-called central ERP system and the resulting procedures and practices need to be changed at the macro level of observation. Actual production planning needs to be changed to consider crucially important parameters as average demand, variability and lead-times at an intermediate level. Operational planning needs to be aware of actual and upcoming demand to be able to ensure availability at the micro level. Allocation of time resources should be shifted away from manual activities.

UDE #3 is caused by similar reasons already identified in the area of semi-finished and finished products. Buffers for raw and packaging material that could protect the supply chain from variability resulting from late deliveries and quality issues are only rarely implemented (see Table 29, 3rd row). Sometimes, cost reduction targets and performance measurement prevent adequate behaviour. Furthermore, the consideration of real demand resulting from production orders being scheduled is lacking. The determination of demand follows an order point system controlled by minimum and maximum stock levels. Change initiatives should address this gap. Manual activities absorb most of the available time so that initiatives addressing quality improvement or opportunities of lead-time reduction remain wishes only.

Current practices regarding buffers need to be shifted away from unresponsive min/max configurations towards effective protections of the supply chain at an intermediate level. Demand planning needs to consider actual demand resulting from well implemented MRP methodology at the micro level. Allocation of time resources should be shifted away from manual activities.

It has already been mentioned that procurement performance is measured based on the resulting level of cost. While this results in orders and sizes not corresponding to actual demand (see Table 29, 3rd row), the negative effect is considered to be smaller than in production. UDE #5 is mainly caused by such performance criteria focussing on local efficiencies (see Table 29, 5th row). A change towards more suitable indicators is expected to have the potential to reduce common lot sizes and by this shrink lead-times. This change is further expected to have a positive influence on turning UDE #1 into the DE #1 shown in Table 31 by freeing up time and machinery resources being necessary for solving first-yield quality issues.

Changes to the current performance measurement of the production function are required to change emphasis away from output towards maintaining availability. The resulting smaller lot sizes are expected to have the potential to reduce lead-times significantly. As a further consequence, idle time can be used to address quality-related issues.

The remaining two UDEs #4 and #6 are again grouped together as their causes are seen to be interrelated. Another feature of this group is that main causes have already been identified during the course of the previous paragraphs in form of lacking integration of information sources and weak or partial MRP implementations and usage (see Table 29, 4th row). The latter point requires many self-developed tools used to satisfy information needs in various functions along the supply chain. Almost all of them have in common that they are operated as islands being only loosely connected or synchronised with the ERP system (see Table 29, 6th row). The resulting issue that results are quite often far away from being optimal becomes obviously true.

Change the whole supply chain implementation including connected functions and systems towards a supportive force to the business. Features to be addressed should include stability, reliability as well as its ability to ensure availability of goods needed.

The preceding discussion of the UDEs identified from the case study together with various parallels obtained from the literature has well addressed the needs of research question one. Since the issues that limit the current performance of production planning and control are now clear, the following discussion of ways to improve the situation follows naturally using some statements already made that represent immediate leanings from the discussion.

6.4 Helpfulness of theory for improvement

This subchapter has the purpose of developing an answer to the second research question trying to determine **to what extent the features of MRP/ TOC/ DDMRP address these limitations** (i.e. the issues at InkCo). Chapter 6.2 has put DEs to be achieved in relation to case findings summarised in Table 30. The achievement of such DEs by converting the existing UDEs is intended to happen by breaking the core cloud explained in the case chapter 4. Instead of repeating the quite general injections of this chapter here, smaller change goals have been picked from the case to allow for a better understanding of the change process. The following Table 32 overleaf presents the ideas, which are further discussed afterwards. Each DE or group of DEs is discussed separately concluded by remarks shown in italics. These remarks also represent recommendations for future improvement activities.

DE	Change goal	Comments
#1 Shortages of finished goods are an exception **#2** Expediting has become an exception	• Strategic inventory positioning • Buffer level determination • Dynamic buffers (frequent recalculation) • Demand-driven planning • Highly visible and replicable execution • Suitable performance measurement	• Absorbing supply and demand variability to maintain flow through the supply chain • Adequate buffer levels consider daily usage, demand, variability and lead-time • Consideration of changing demand patterns and seasonality • Direct consideration of open orders, buffer levels that need replenishment, components demand (produced and purchased) • Clear rules for priorities by due dates with execution horizon, buffer visibility and inventory alerting • Often smaller but adequate lot sizes reduce resource occupation and frees up time for projects and problem-solving
#3 Shortages of raw materials are an exception	• MRP connects demand for finished goods to demand for raw materials • Strategic inventory positioning • Reduce lead-time and quality issues	• Full implementation of MRP that considers all relevant levels of the BOM until procurement • Absorbing supply variability to maintain flow through the supply chain • Use free time to address important issues
#5 Production lead-times are significantly shorter	• Demand-driven planning and highly visible and replicable execution • Strategic inventory positioning • Adequate performance measurement criteria	• Lot sizes are mainly determined by considering demand from open orders and replenishment needs and not inadequate performance criteria • Reduces exposure to stock-outs and has the potential to shrink lead-times • No focus anymore on local efficiencies
#4 Production plans are stable and according to actual demand **#6** DDP of excellent level achieved	• DDMRP implementation • Interconnectedness of all relevant functions	• Clear priorities and dynamic plans within execution horizon, clear priorities by due date, reduced need for changes or expediting by stabilization of supply chain • Maximization of information availability to planning and control

Table 32 – From change targets to DEs

The DE #1 and #2 to be achieved are connected in a similar way as in the previous subchapter. Therefore, the change targets to be achieved as enabling measures are discussed together. It has been identified that protection of the supply chain from process and supply variability is a requirement for arriving at good levels of availability (see Table 30, 1st row). This can be achieved by introducing buffer management in two different variants. First, strategic inventory positioning establishes this protection addressing variability resulting from suppliers and internal issues (e.g. machinery breakdowns). Second, adequate buffers for finished products provide protection from demand variability on the customer side.

Furthermore, the first measure is also able to protect from demand variability to an extent if protection from buffers is not sufficient and a production order needs to be initiated urgently. Initial demand (i.e. raw and packaging materials) or intermediate demand (i.e. semi-finished goods) are held as inventory buffers where appropriate, but are also replenished or produced according to actual demand (see Table 30, 3rd row). This is ensured by a proper implementation of the MRP functionality. This leads to the core component of DDMRP being demand-driven planning (see Table 30, 2nd row). Clear priorities are in effect that consider demand for customer orders and such for replenishing buffers by due date. The impact of the problem at InkCo in form of inadequate planning of quantities at SKU level gets reduced by this feature, since one starts at a reasonable buffer level and monitors and acts timely by adjusting the buffer to actual requirements. Finally, this integrated information processing and planning environment makes production load visible in form of the current lead-time. This enables sales to respond to customer orders with a reliable delivery date (see Table 30, 4th row). The remaining quality issues have already been identified to consume time and other resources to be adequately addressed and hopefully solved. The resulting stabilization of the supply chain together with expected lower levels of resource utilization should help to allocate this time needed. As an ultimate consequence of introducing such extensive changes to current ways of working, the resulting goals should stand at the center of new performance measurement criteria. Since all causes of the initial UDEs are successfully addressed, the intended DEs are achievable by the measures described.

The introduction of the DDMRP methodology has the potential to improve finished products' availability significantly as well as to reduce expediting to a minimum. It requires extensive changes to current ways of performance measurement to encourage appropriate behavior.

Addressing DE #3 can be easily done by referring to the comments made for first two DEs as DDMRP embraces standard MRP and integrates it into its wider set of functionality (see Table 30, 3rd row). Furthermore, strategic inventory positioning has already been identified as helpful for improving availability along the supply chain. However, both intended improvements delivered by DDMRP functionality require changes to current performance measurement criteria that mainly focus on reducing cost. Here, a shift towards availability makers perfectly sense. Finally, free time resources expected to become available once MRP and DDMRP components help to reduce manual work should be invested into projects addressing quality and lead-time problems as of today. Ideas include quality checks before shipment, more frequent deliveries or closer collaboration including stock visibility. Altogether, the change goals related to DE #3 are addressed by the goals relevant to DE #1 and #2.

Demand-driven planning and highly visible and replicable execution define clear rules for priorities and lot sizes (see Table 30, 2nd row). The latter is determined by demand resulting from open customer orders or replenishment needs of buffers only. It is expected that this results in lot sizes being on average smaller than today. While this has a positive effect on reducing lead-times on its own, the introduction of strategic inventory positioning complements this effect due to reasons already described in relation to DE #1 and #2. Finally, UDE #5 is at least partly caused by performance criteria focussing on local efficiencies (see Table 29, 5th row). Therefore, changing these criteria towards more suitable indicators focussing on availability rather than on output or capacity utilisation is required.

It is in the focus of DDMRP to shrink lead-times down by various measures including demand-driven planning and strategic inventory positioning. Changes to the current performance measurement of the production function moving the emphasis away from output towards maintaining availability are sought. The resulting smaller lot sizes are expected to have the potential to reduce lead-times significantly.

The remaining two DEs #4 and #6 are grouped together in a similar way as the first two since their change goals are seen to be interrelated. DDMRP is of central importance to create an environment where clear rules about information consideration and decision-making ensure the ability to plan in a reliable way (see Table 30, 2nd row). The first point requires a well-designed ERP system based on a central database that allows for optimal provision of information.

The supply chain needs to be implemented on the basis of an adequate ERP system that ensures information provision of high quality and provides the ground for a successful DDMRP integration.

It should be clear now that DDMRP has the potential to improve the performance of production planning and control at InkCo in a desirable way. The previous discussion of DE-related initiatives has shown this by using DDMRP elements as concrete measures to solve current problems or issues. However, since this discussion was mainly based on applying theory to practice, considering the results of the simulation chapter allows for even better justification of DDMRP by using near-practice findings from the simulation to solve practice issues.

In order to achieve the DEs #1 and #2, theory suggests to use DDMRP functionality in general and demand-driven planning in particular. The simulation has shown that such practices provide clear rules for planners to follow. The overall result has shown beneficial effects on the system stability and by this on the ability to deliver. However, the need to interpret the concrete results in a careful way should be repeated here. The real results of 2013 cannot solely be attributed to the lacking system functionality or MRP faults, but needs also to be seen as the result of suboptimal current practices.

The simulation did not directly address the needs of DE #3. However, the clear decision rules together with the highly visible execution component of DDMRP allows for predictability assisted by projected on-hand balances and well adjusted lead-times and order quantities. Furthermore, the strategic inventory positioning component of DDMRP is expected to be of further help.

It has already been stated that the simulation has not shown a general tendency to reduce stock levels, but to reduce batch sizes. Since the simulation has only considered a selection of some SKUs, the result of DDMRP application on the whole product line needs to remain open. However, reducing the visible tendency to favour large batches over more frequent setups and cleanings required for product changes has surely the potential to free up production time and by this reducing overall lead-time. Therefore, the achievement of DE #5 by DDMRP practices could be supported by the simulation results.

Finally, the stability of plans sought by DE #4 is supported by DDMRP shown in the simulation. However, one needs to define stability in a different way from the common understanding of being fixed. Stability in its new meaning has to do with doing the right thing at the right time. Demand-driven planning that follows clear rules is visible and replicable. The single goal of improving due-date performance by ensuring availability demands for this. This can easily mean that during peak times one has to accept more changes than during more relaxed parts of the year. Furthermore, lead-time corresponding to the actual load could be of variable length in relation to the open demand. The case has uncovered that people mean clear rules and priorities when asking for stability. This is what DDMRP can give to them.

Based on the common understanding created in the preceding discussion of the case analysis and the simulation, it is now possible to state the answer to the second research question about the potential of MRP, TOC or DDMRP concepts to help improving current performance levels. As a reminder, Ptak and Smith's (2009) rule is repeated here: "The effectiveness of any system has to be judged by the result it achieves."

It has been shown that DDMRP embraces MRP, which is one of its most important components. Furthermore, DDMRP cannot and does not suppress the fact that it is largely influenced if not based on various elements of the TOC methodology, which has already been shown previous parts of this document. The discussion in this subchapter has proven the value of DDMRP to InkCo by identifying its potential to turn UDEs into DEs and by this improving the current situation. Particularly the simulation has shown in a very practical way that results can be improved significantly. Therefore, the effectiveness of DDMRP needs to be assessed as positive since its features address the current limitations in an effective way.

6.5 Assessment of generalizability

The case study together with the simulation has shown that DDMRP has the potential to stabilise a production planning and control system in a manufacturing business. In detail the benefits were adjusted stock levels towards demand in order to support and increase availability. As an appreciable side effect DDMRP has given a common theme or structure for everybody to follow that defines production-related decision-making.

Stock levels have been determined by buffers that consider usage (ADU), lead-time and variability. The concept explicitly considers the need to assess the validity of buffers over time in order to reflect changing demand patterns. Availability could have been improved by implementing such buffers and related decision-making together with supporting measures as strategic inventory positioning and highly visible and replicable execution.

Most if not all elements just mentioned are very broad and general in their nature, which allows them to stay valid in many manufacturing contexts. Furthermore, the heart of demand calculation is still MRP that is used as a standard instrument in the vast majority of manufacturing businesses anyway. Therefore, real evidence can neither be found nor stated that narrows or reduces the applicability of these concepts to a wider range of businesses.

However, applicability is one thing and the proven ability to improve a specific situation might be something different. This claim becomes obviously true since one thinks about the different and almost unique situations companies are facing. They are shaped by many factors including the industry, the level of competition, the nature of demand, the maturity of the organisation, the attitudes of its management and many more. Furthermore, each company is also suffering from common MRP weaknesses in a very unique way. Finally, the current usage of system tools and the related ways of working are not always in an optimal state. Therefore, the benefits DDMRP might deliver to a specific organisation can be wide spread depending on the specific starting position. However, as current conditions can always change, DDMRP might also have a different value measured in its ability to improve over time in correspondence the situation a company is facing at any point in time.

This means that the findings of this research project are not generalizable in full to any other company due to its uniqueness and the resulting benefits. Nevertheless, this means also that neither a wide range of applicability nor certain impact on the organisational performance can be denied. However, no case can be imagined where DDMRP might harm a company and its business performance once being implemented properly. Altogether, the concrete effect depends directly on the unique circumstances.

7 Conclusions

In the first chapter of this document, the MRP methodology was explained from its origins over its various evolutionary improvements steps until its recent applications in current ERP systems as still being a core functionality. It could be justified that improvements have only addressed the integration into the wider environment of ERP systems instead of improving the embedded algorithms. This is the main reason for its difficult application in today's environments since its core principle follows a push and promote style rather than the pull-based principles sought in many volatile business environments. To contrast these deficiencies with ideas derived from continuous improvement, the TOC methodology is reviewed. Beside the fact that TOC always tried to address the push versus pull conflict by promoting pull-based instruments and related thinking, it offers useful strategies and tactics relevant to most manufacturing environments from strict MTO over mixed configurations until MTS scenarios. However, TOC is lacking adequate software that facilitates implementation and later operation of such methods. In an attempt of integration, the quite recent methodology of DDMRP is put in relation to its MRP and TOC roots to show that it addresses the main weaknesses of the aforementioned methodologies. It draws from its famous parents in a way that creates something not very new but easy to understand that consists of only a few main components and rules that promise to improve production planning and control in a dramatic way.

The second chapter of the document is intended to prepare the actual research task by reviewing theory and developing a research plan. A brief review of common methodologies leads to the justification of choosing a realist approach due to its appropriateness for operations research tasks having a strong problem-solving component. Following this, a brief review of common qualitative and quantitative research methods leads to the justification of single-case study research enhanced by simulation as the appropriate method for this research project. Relevant instruments used in this study are presented briefly followed by an evaluation of the study design. Adequate levels of reliability and validity can be attested to this study, which proves the design to be appropriate and in line with the study needs. Based on the research design, the main sources and ways of collecting data are presented. Mixing of methods like personal observation, semi-structured interviews, small-scale surveys and databases have the potential to enhance the quality of the later case study description and analysis. Finally, the data analysis is described as a three-stage process. First, the case is produced and analysed, which creates an adequate level of understanding. Second, the case findings are analysed to determine the degree of fit with generic templates derived from the literature. Third, a simulation activity is intended to show practical fit of the improvement methodology with the specific settings of the case company. A presentation of the data collection activities rounds up the chapter.

After having prepared the ground by identifying relevant theories and by developing a comprehensive research plan, the next chapter presents the case of InkCo. It starts by describing the company in its environment and continues by identifying how demand is determined at the company today. This part concludes with the finding that InkCo's operations and management is strongly dominated by financial measurements. This is further supported by the next part, which looks closer at the organisational functions of procurement, production and logistics. Here, strong influence of budgets and cost control become visible that seem to be inappropriately used, because they are not delivering the required results in terms of adequate product availability rates. The results are condensed down into six UDEs that cover the main issues at the case company's production planning and control function. The resulting current reality tree connects the UDEs to the core conflict in form of a cloud. The next part of the chapter tries to develop suitable injections or actions that are able to break the cloud shown before. As a result, the introduction of DDMRP as an overall system for production planning and control seems to be able to turn the undesirable effects resulting from the current ways of working into desirable effects.

The next chapter continues the development of an improved system by simulating DDMRP on the basis of real data taken from InkCo's ERP system. It shows the strong effect of DDMRP on availability in form of almost dramatic improvements. Although concrete results need to be interpreted in a careful way, because they are also influenced by the quality of current ways of working. DDMRP provides a standardised system of decision-making that replaces experience and intuition by facts based on stock levels, lead-time, consumption over lead-time and variability. Although, a general reduction of stock levels could not be found, stock levels become appropriate in relation to the need resulting from customer orders. The result could be seen as a stabilised system being responsive to the needs of the market.

Concluding the case and simulation chapters, the next chapter is intended to develop the answers to the two research questions. To prepare the ground, the chapter starts by putting the findings resulting from the previous two chapters in relation to the identified UDEs and relevant pieces of theory. It continues by summarising the case analysis under the categories of procurement, production planning and control, stocks and availability. This part is logically rounded up by putting expected positive effects resulting from the proposed changes in relation to desirable effects and again relevant theory.

Based on the previous information, the development of the answer to the first research question about **what the issues are in InkCo's current planning and control system that limit performance** becomes possible. The answer mainly deals with the identification of undesirable or performance-limiting effects or elements of the current system. First of all, the weak implementation of the current ERP system that does not consider demand, variability and resulting lead-times in an adequate way is a major issue. The results are frequent shortages of finished goods and excessive levels of expediting. Furthermore, MRP does not consider semi-finished goods and raw materials in an integrated planning approach, which further limits their availability. The aforementioned almost permanent expediting mode causes lead-times longer than necessary. Moreover, individual as well as departmental performance measurement focuses on local efficiencies, which further prolongs lead-times by unnecessarily large batch sizes. All these factors cause a certain system instability that is represented by production plans with a very limited lifetime. Overall, a certain kind of chaos is visible when observing production planning and control over time. This chaotic environment can be further characterised by the fact that managers are almost permanently oscillating on priorities between pure push based forecasts and more pull based demand driven planning patterns.

The answer to the second research questions tries to determine **to what extent the features of MRP/ TOC/ DDMRP address these limitations** (i.e. issues) at InkCo. The answer mainly draws from the case analysis and the simulation and considers the degree to which the mentioned concepts are able to turn the identified UDEs into desirable effects (DEs). The literature review has shown that DDMRP includes MRP and that it draws from TOC ideas in various ways. By doing this, DDMRP uses the concepts it is based on in a way that is capable of delivering more than single concepts being applied. Thus, the introduction of DDMRP has been found to be capable of delivering the improvements of availability and stability of the system sought. As another appreciable effect, the reduction of lead-times supported by various elements of DDMRP (e.g. strategic inventory positioning or smaller lot sizes) needs to be mentioned. However, one needs to be aware of the need to interpret the results carefully.

The degree of improvement depends on the initial situation, which could often be characterised by poor practice and inadequate system implementations. Although this initial situation could not been fully analysed and described by monetary figures showing the waste in form of wrong system usage or inadequate decision making, the case has provided many indicators for this.

The identification of performance limiting issues shown in the answer to research question one has provided a picture of a manufacturing company that might be unique in its product portfolio, cost structure or competitive advantage. However, taking a more helicopter-style view on InkCo might provide the view that InkCo is not that unique and that there are many more companies being in a similar situation and suffering from comparable issues. Standard MRP is in operation as in so many companies too. It has its common problems that have been identified in the literature review and have been found in the case study. Elements of organised continuous improvement have not been found to be part of standard procedures as in so many medium-sized companies. InkCo is profitable and could even deliver better results once main issues are addressed properly, which has not happened in the past for many reasons including lacking knowledge or motivation, inadequate software tools and missing awareness of the root causes. DDMRP is a recent concept that is not that new at all. It embraces concepts and lessons learned during the last decades and places them in a unique way. By this, it uses the best from them to form a coherent system for production planning and control. Since many components as MRP, buffer management and continuous improvement are at least known to a wider audience, it seems to be an solution to the common problems manufacturing companies are facing today. The case analysis as well as the simulation have provided some indicators that support this claim. The main contribution of this research is the finding that DDMRP has the potential to improve the performance of a manufacturing company supported by its incorporation of already known ideas and tools and its simplicity. It represents a strategy valid for companies facing today's market volatility and customer needs by being an on-going activity further supported by its dynamic and continuous improvement character. It uses the well-known concept of buffer management in various areas to protect the supply chain from various forms of volatility. Although findings are specific to the case company, they could be a trigger for more researchers to focus on DDMRP and by this delivering more evidence about its potential and the author's hope for wider generalizability. Some thoughts about the latter are further explained in the following paragraph.

As a final remark, some thoughts should be made regarding the validity and replicability of the findings made and presented. It has already been identified that currently literature about DDMRP implementation and likely results is rare. This makes comparing results of this research with findings made by others almost impossible. Nevertheless, findings presented have been developed by application of well-established methods and techniques and are expected to stay valid until further information becomes available. The resulting generalizability needs to be seen in a similar way. Applicability is seen to be generally given but resulting value depends on the specific and unique situation of the adopting company.

Glossary of Terms and Abbreviations

ADU	Average daily usage
ASR	Actively synchronized replenishment
ASRLT	Actively synchronized replenishment lead-time
ATP	Available to promise
BI	Business intelligence
BM	Buffer management
BOM	Bill of material
CCPM	Critical chain project management
CCR	Capacity constrained resource
CF	Cash flow
CLR	Categories of Legitimate Reservation
CLT	Cumulative lead-time
CPFR	Collaborative planning and forecasting
CRM	Customer relationship management
CRT	Current reality tree
DBR	Drum-buffer-rope
DDMRP	Demand driven manufacturing requirements planning
DDP	Due-date performance
DE	Desirable effect
EC	Evaporating cloud
EOQ	Economic order quantity
ERP	Enterprise resource planning
FRT	Future reality tree
GA	General and Administrative
I	Inventory
IDD	Inventory dollar days

IT	Information technology
MLT	Manufacturing lead-time
MOQ	Minimum order quantity
MPS	Master production schedule
MRP	Manufacturing requirements planning
MRP II	Manufacturing resource planning
MTA	Make to availability
MTO	Make to order
MTS	Make to stock
NP	Net profit
OE	Operating expenses
OPT	Optimized production technology
OTOG	Over top of green
PLT	Production lead-time
POOGI	Process of ongoing improvement
PRT	Prerequisite tree
QLT	Quoted lead-time
ROA	Return on assets
ROI	Return on investment
ROS	Return on sales
S-DBR	Simplified drum-buffer-rope
S&OP	Sales and operations planning
SC	Supply chain
SCM	Supply chain management
SKU	Stock-keeping unit
SQL	Structured query language

TA	Throughput accounting
TDD	Throughput dollar days
TP	Throughput
TOC	Theory of Constraints
TOG	Top of green
TOR	Top of red
TOY	Top of yellow
TT	Transition tree
UDE	Undesirable effect
VMI	Vendor managed inventory
WIP	Work in progress
Y2K	Year 2000

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Appendices

Appendix 1 – Aide-mémoire procurement

Purchasing activity

- Types of material
- Suppliers involved
- Basis for demand planning
- Ways of working
- Contractual versus ad hoc organisation
- Inventory and lead-times
- Role of technology

Performance measurement

- Reliability of supply
- Supplier performance
- Quality issues

Undesirable effects

- What are major issues?
- What are likely causes of them?
- Are there ideas for improvement?
- Are there any hindrances?
- How to implement the change?
- Why has nothing been done yet?

Appendix 2 – Aide-mémoire production

Manufacturing

- Processes and sequence
- Organisation and factory layout
- Planning and lead-times
- Role of inventory and batch sizes
- Sources of variation (Demand, machinery breakdowns, quality problems, raw and input availability, …)

Performance measurement

- Production order fulfilment (overproduction, expediting and stock outs)
- Plan changes
- Output
- Production cost (setups, breakdowns, quality)
- In-process quality management

Undesirable effects

- What are major issues?
- What are likely causes of them?
- Are there ideas for improvement?
- Are there any hindrances?
- How to implement the change?
- Why has nothing been done yet?

Appendix 3 – Aide-mémoire logistics and sales

Business composition

- Standard business versus promotions
- Contractual versus flexible organisation
- Order structure (lead-time, seasonality, …)
- Shipment methods and related lead-times
- Role of technology

Performance measurement

- Budgets
- Due-date performance
- Stock out occurrences
- Quality

Undesirable effects

- What are major issues?
- What are likely causes of them?
- Are there ideas for improvement?
- Are there any hindrances?
- How to implement the change?
- Why has nothing been done yet?

Appendix 4 – Aide-mémoire planning

Production planning

- Role of budgets
- Demand recognition
- Organisation and factory layout (capacity and routing)
- Planning and lead-times
- Role of inventory and batch sizes
- Sources of variation (Demand, machinery breakdowns, quality problems, raw and input availability, MTO vs. MTS conflicts, …)

Performance measurement

- Production order fulfilment (overproduction, expediting and stock outs)
- Plan changes
- Output (local efficiencies)
- Production cost (setups, breakdowns, quality)
- In-process quality management

Undesirable effects

- What are major issues?
- What are likely causes of them?
- Are there ideas for improvement?
- Are there any hindrances?
- How to implement the change?
- Why has nothing been done yet?

Appendix 5 – Questionnaire procurement

1 Process indicators procurement

Procurement staff

Number of employees	
Activity share for procurement in % of working time	

Purchasing volume per year

Number of purchased parts	
Amount in EUR	
Number of requests	
Number of purchase orders	
Proportion of orders via the Web (portal or similar) in %	
Number of deliveries	
Number of framework agreements	
Proportion of material deliveries resulting from framework agreements in %	
Number of supplier invoices	
Number of supplier returns	

Active suppliers		Proportion of extended workbench
Domestic suppliers		
EU suppliers		
Non-EU suppliers		

What is the delivery performance of suppliers?

What is the proportion of cost of materials in relation to COGM?

Is the profitability of merchandise products known? ☐ Yes ☐ No

2 Process description

Purchasing / Procurement	
Number of employees:	**Effort / Activity share** *(in % of total working time)*:
Creates and maintains the procurement budget for - selected product groups and / or - buyer	
Accepts order proposals from MRP	
Changes / amends / groups the order proposals	
Selects the supplier for the orders and assigns the supplier to the order proposals, provided that no supplier has been assigned automatically	
Considers supplier evaluations	
Creates manual order proposals as specifications for purchasing products and services	
Creates order proposals for - Disposal - Empties	
Assigns order proposals to any existing framework contract	
Releases the order proposals to purchasing	
Creates purchase orders - without supplier master data - without material master data - from order proposals - from supplier quotations - with order line prices - with order line quantities - divided into several partial deliveries	
Creates - delivery schedules - Calls for delivery framework contracts	
Totals demand for one product resulting in one order line	
Considers - quantity and / or value depended increases and decreases in an order line - Deviating standard order quantities or multiplies - Deviating price units e.g. quantities, length, price per unit - existing purchasing framework agreements	
Recognises the demand source from the order proposal	

Abridged version

4 Potentials

Please describe the aspects of processes that need to be changed in detail.

Entry column "implementation time": "immediately" or "during ERP project" or "after going live"
Entry column "implementation cost": "low", "medium", "high", "very high"
Entry column "Value assessment": "low", "medium", "high", "very high"
Entry column "ERP/Orga.": "ERP", "ERP/Orga.", "Orga."

Name	Description	Utility	Implementation time	Implementation cost	Value assessment	ERP / Orga.
Purchasing with ERP functionality	*In the future there is no purchase order anymore outside of the ERP system*	*Increasing visibility, safe and consequent implementation of the purchasing process until invoice verification*	*during ERP project*	*low*	*high*	*ERP*

Appendix 6 – Questionnaire production

1 Process indicators production

Number of employees in production

Number of employees			
Proportion of total working time in %			

Number of production orders per day / week	
Number of confirmations per day / week	
Number of work schedules	
Number of lines per work schedule	
Number of machines in operations	
Number of tools in operations	
Ability to ship on time (relationship between customer requested date and confirmed shipping date)	
Due-date performance (relationship between confirmed and actual shipping date)	
Value of work in process	

How are working ours defined in production?
(Please tick only one answer!)
☐ daily working time
☐ Weekly / monthly flextime with core working hours
☐ group work / semi-autonomous teams
☐ shift work

Does permanent overtime exist in production? ☐ Yes ☐ No

If yes, in what areas?

There are reports that indicate which machines / work centres have become bottlenecks recently or will likely become bottlenecks in the near future.
(1) not correct … (5) fully correct

	1	2	3	4	5
Currently:					
Target value:					

Clear information on the utilisation of machinery and workers are available.
(1) not correct … (5) fully correct

	1	2	3	4	5
Currently:					
Target value:					

Reliable decision aid tools are available to support make or buy decisions.
(1) not correct … (5) fully correct

	1	2	3	4	5
Currently:					
Target value:					

Information about rejection rates are available in form of KPI and are easily accessible.
(1) not correct … (5) fully correct

	1	2	3	4	5
Currently:					
Target value:					

Hourly rates are available from cost accounting.
(1) not correct … (5) fully correct

	1	2	3	4	5
Currently:					
Target value:					

Abridged version

4 Potentials

Please describe the aspects of processes that need to be changed in detail.

Entry column "implementation time": "immediately" or "during ERP project" or "after going live"
Entry column "implementation cost": "low", "medium", "high", "very high"
Entry column "Value assessment": "low", "medium", "high", "very high"
Entry column "ERP/Orga.": "ERP", "ERP/Orga.", "Orga."

Name	Description	Utility	Implementation time	Implementation cost	Value assessment	ERP / Orga.
Reliable delivery date determination	*Determining the delivery date while taking into account resource availability (material and capacity) as well as already released or even begun production orders*	*Determination of a delivery date that considers the actual load of manufacturing as with a high probability -> increased customer satisfaction*	*during ERP-project*	*low*	*high*	*ERP*

Appendix 7 – Questionnaire logistics

1 Process indicators logistics

Number of employees in logistics

Number of employees	
Proportion of total working time in %	

Number of warehouses	
Number of pallet lots per warehouse	
Number of pallets receipt per week (average)	
Number of pallets dispatched per week (average)	
How are safety stocks determined?	

IT helps to optimise stock levels and to reduce inventory costs?

(1) poorly … (5) very good

	1	2	3	4	5
Currently:					
Target value:					

2 Process description

Which of the following activities are carried out routinely?

Stock management	
Number of employees:	**Effort / Activity share** *(in % of total working time)*:
Warehouse structure according to - plant / factory - storage location - storage area / pallet lot	
Warehouse type distinguished by - single storage - bulk storage - high-bay racking with coordinates - aisle - row - bay	
Indicates the storage type by considering the goods stored being: - finished products - semi-finished products - raw materials - spare parts - goods receipt - picking - shipping - customs - residues / dawn - blocked goods / quarantine - quality inspection - customer returns - supplier returns - second-rate materials - customer consignment - supplier consignment - material at extended workbench supplier - pallets - cold storage - Hazardous substances - alcohol - disposal	
Differentiated storage area type - single product per - various products - batch-wise storage - shelf life groupings (for different batches per shelf life)	
stores - one product - one batch - at multiple warehouses	

Abridged version

4 Potentials

Please describe the aspects of processes that need to be changed in detail.

Entry column “implementation time“: “immediately“ or “during ERP project“ or “after going live“
Entry column “implementation cost“: “low“, “medium“, “high“, “very high“
Entry column “Value assessment“: “low“, “medium“, “high“, “very high“
Entry column “ERP/Orga.“: “ERP“, “ERP/Orga.“, “Orga.“

Name	Description	Utility	Implementation time	Implementation cost	Value as-sessment	ERP / Orga.
Automatic stock parameter configuration	*Automatic determination of minimum, safety and maximum stock levels per product according to consumption*	*Increased due-date performance*	*during ERP-project*	*low*	*high*	*ERP*

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Appendix 8 – Questionnaire planning

1 Process indicators of production planning

Number of employees in manufacturing

Departments involved			
Number of employees			
Proportion of total working time in %			

For how many finished products production planning is carried out?

Intervals at which production planning is performed?
(You may tick more than one answer!)
☐ weekly
☐ monthly
☐ quarterly
☐ annually
☐ other:

How long does the process of production planning usually take?

How do you asses the accuracy (deviation from plan to actual) of production planning?
(1) poor … (5) very precise

	1	2	3	4	5
Currently:					
Target value:					

2 Process description

Which of the following activities are carried out routinely?

Demand planning	
Number of employees:	**Effort / Activity share** *(in % of total working time)*:
Creates a sales statistic	
Creates sales statistics according to - customer groups / customers - product groups - with comparison of previous year / current year - with selection of from / to date - with drill-down functionality	
Aggregates product sales according to various criteria - sales regions - time periods - customers / customer groups	
Creates a period-related sales plan (e.g. annual sales plan)	
Considers specifications - manually - from sales plan - from results plan - from historical data	
With amendment option	
Adjusts the forecast	
Highlights exceptions	
Considers exceptional cases within demand planning - introduction of new products - discontinued products - changes in the marketing strategy - promotional activities - seasonality	
Defines the forecasting method by using special software tools	
Calculates a sales forecast with - multipliers - moving average - weighted moving average - exponential smoothing 1^{st} order - variable prediction horizon - parameterization using patterns	

5 Potentials

Please describe the aspects of processes that need to be changed in detail.

Entry column “implementation time“: “immediately“ or “during ERP project“ or “after going live“
Entry column “implementation cost“: “low“, “medium“, “high“, “very high“
Entry column “Value assessment“: “low“, “medium“, “high“, “very high“
Entry column “ERP/Orga.“: “ERP“, “ERP/Orga.“, “Orga.“

Name	Description	Utility	Implementation		Value assessment	ERP / Orga.
			time	cost		
Integrated production planning	*Replacement of Excel based production planning through ERP integrated production planning*	*Increasing of process quality and efficiency by avoiding double data maintenance*	*during ERP project*	*low*	*high*	*ERP*

Appendix 9 – Buffer level calculation

Ptak and Smith (2011) provide recommendations for calculating the size of the green zone (in absence of significant MOQ) and the red zone base buffer components. The following table shows their values:

	Green zone impact	Red zone base impact
Long lead-time	20-40% ADU over LT	20-40% ADU over LT
Medium lead-time	41-60% ADU over LT	41-60% ADU over LT
Short lead-time	61-100% ADU over LT	61-100% ADU over LT

They have also provided recommendations for calculating the red zone safety component of the red buffer. The following table provides their values:

	Red zone safety impact
High variability	60-100% red zone base
Medium variability	41-60% red zone base
Low variability	20-40% red zone base

Appendix 10 – Sample SKUs

The wish to undertake a simulation of a new and hopefully more suitable production planning and control methodology has been stated during the interviews. As a consequence, the manager in charge of this function was asked to suggest a set of SKUs, which covers all product groups of InkCo as well as all categories of products in terms of lead-time, variability and volume. The following table shows this initial input to the simulation activity.

SKU	Package	Type
ADSP1	1KG	Normal
ADSP2	1KG	Normal
ADSP3	1L	Normal
ADSP4	5L	Normal
ADSP5	1KG	Normal
ADSP6	1L	Slow mover, 1 x prod in 2012
ADSP7	1L	Slow mover, 1 x prod in 2012
ADSP8	1L	Slow mover, 1 x prod in 2012
ADSP9	1L	Normal
ADSP10	800g	Normal
ADSP11	1L	Normal
DDDP1	1L	Normal
DDDP2	1L	Normal
DDDP3	1L	Normal
DDDP4	1L	Normal
DDDP5	1L	New product
DDDP6	1L	New product
DDDP7	1L	New product
DDDP8	440ml	Normal
DDDP9	440ml	Normal
DDDP10	1L	Normal
ADSP12	5KG	Normal
ADSP13	5KG	Normal
ADPP1	1L	Normal
ADPP2	1L	Normal
ADPP3	1L	Normal
ADPP4	1L	Slow mover, 1 x prod in 2012
ADPP5	1KG	Normal

Normal is defined as an SKU that was produced and sold in 2012. Slow movers were only produced once in 2012 and new products did not exist back in 2012.

Based on the material movement data taken from the current ERP system, the following information were extracted to be able to perform calculations related to DDMRP. The following table shows the results.

SKU	Ø batch size	Min batch size	Max batch size	Time interval	LT category	ADU	Stddev	Variab. class
ADSP1	1111.24	529.33	1573.67	12	Medium	138.81	41.23	Low
ADSP2	978.61	918	1040.5	26	Long	72.75	36.95	Low
ADSP3	940.45	660.67	1012	32	Long	29.9	10.38	Low
ADSP4	173.01	68.13	203	36	Long	5.32	1.56	Low
ADSP5	676.91	132	1068	10	Medium	304.22	97.41	Low
ADSP6	43	43	43	365	Medium	3.49	2.09	Medium
ADSP7	44	44	44	365	Medium	4.98	4.03	Medium
ADSP8	25	25	25	365	Medium	2.9	2.94	High
ADSP9	319.24	315	322.67	28	Medium	57.79	30.45	Low
ADSP10	451.31	444.5	457.5	32	Medium	33.47	13.99	Low
ADSP11	732.91	475.86	1121	6	Medium	242.33	51.19	Low
DDDP1	77.33	26	149	72	Medium	10.08	12.29	High
DDDP2	50,67	8	88	77	Medium	7.24	10.84	High
DDDP3	63	63	63	62	Medium	10.47	13.92	High
DDDP4	31	31	31	365	Medium	9.17	14.34	High
DDDP5	0	0	0	365	Medium	0	0	High
DDDP6	0	0	0	365	Medium	0	0	High
DDDP7	0	0	0	365	Medium	0	0	High
DDDP8	214	199	229	70	Medium	40.31	30.78	Medium
DDDP9	223.5	202	245	67	Short	36.99	32.2	Medium
DDDP10	82	30	134	10	Medium	8.9	10.79	High
ADSP12	175.25	100	251	56	Medium	7.49	5.11	Medium
ADSP13	150.67	60	252	88	Medium	8.27	4.18	Low
ADPP1	66.67	64	72	80	Medium	6.26	5.57	Medium
ADPP2	63	63	63	365	Medium	3.93	4.49	High
ADPP3	75.5	75	76	131	Medium	4.87	5.18	High
ADPP4	0	0	0	365	Medium	3.09	6.53	High
ADPP5	359.85	355	362.5	17	Medium	37.34	10.54	Low

To be better able to understand the table and the decisions made to arrive at the category and class useful for the later buffer determination, some comments need to be made.

Ø batch size:	average over all productions in 2012
Min batch size:	smallest production batch in 2012
Max batch size:	largest production batch in 2012
Time interval:	Time period between actual productions in 2012
LT category:	Short for less or equal 9 days, Medium for greater 9 and less or equal 29 and Long for greater than 29 days (corresponds roughly to InkCo's categories of 1 week, 1 month and the rest)
ADU:	Average daily usage in 2012
Stddev:	Standard deviation from ADU
Class:	Variability class resulting from the fraction of stddev in relation to ADU (Low for less or equal 55%, Medium for greater than 55% and less or equal 100%, High for greater than 100%)

Appendix 11 – DDMRP buffer calculation

Since this is the very beginning of a simulation activity, buffers for lead-time impact are set to the middle of the suggested ranges shown in Ptak and Smith (2011). The resulting impact figures are shown in the next table.

	Green zone impact	Red zone base impact
Long lead-time	30% ADU over LT	30% ADU over LT
Medium lead-time	50% ADU over LT	50% ADU over LT
Short lead-time	80% ADU over LT	80% ADU over LT

For the same reason of having no real experience at the beginning of the intended simulation activity, the red zone safety component of the red buffer will be calculated by using middle values of the recommendations of Ptak and Smith (2011). The following table provides their values:

	Red zone safety impact
High variability	80% red zone base
Medium variability	50% red zone base
Low variability	20-40% red zone base

The next table shows the calculation of the buffer zones based on the assumption that no ordering policy exists for any item.

SKU	ADU	LT	ADU * LT	LT category	Green zone	Red zone base	Yellow zone	Variab. class	Red zone safety
ADSP1	138.81	15	2082.15	50	1041	1041	2082	30	312
ADSP2	72.75	30	2182.5	30	655	655	2183	30	196
ADSP3	29.9	30	897	30	269	269	897	30	81
ADSP4	5.32	30	159.6	30	48	48	160	30	14
ADSP5	304.22	10	3042.2	50	1521	1521	3042	30	456
ADSP6	1.35	20	27	50	14	14	27	50	7
ADSP7	1.98	20	39.6	50	20	20	40	50	10
ADSP8	1.9	15	28.5	50	14	14	29	80	11
ADSP9	37	10	370	50	185	185	370	30	56
ADSP10	33.47	20	669.4	50	335	335	669	30	100
ADSP11	242.33	10	2423.3	50	1212	1212	2423	30	363
DDDP1	7.28	20	145.6	50	73	73	146	80	58

DDDP2	5.24	20	104.8	50	52	52	105	80	42
DDDP3	7.47	10	74.7	50	37	37	75	80	30
DDDP4	5.17	10	51.7	50	26	26	52	80	21
DDDP5	1	10	10	50	5	5	10	80	4
DDDP6	1	10	10	50	5	5	10	80	4
DDDP7	1	10	10	50	5	5	10	80	4
DDDP8	30.31	15	454.65	50	227	227	455	50	114
DDDP9	36.99	5	184.95	80	148	148	185	50	74
DDDP10	8.9	10	89	50	45	45	89	80	36
ADSP12	7.49	15	112.35	50	56	56	112	50	28
ADSP13	8.27	15	124.05	50	62	62	124	30	19
ADPP1	6.26	10	62.6	50	31	31	63	50	16
ADPP2	3.93	15	58.95	50	29	29	59	80	24
ADPP3	4.87	15	73.05	50	37	37	73	80	29
ADPP4	3.09	15	46.35	50	23	23	46	80	19
ADPP5	37.34	20	746.8	50	373	373	747	30	112

ADU’s and variability classes for new products have been anticipated by consulting marketing budgets. Lead-times for such products were taken from production records.

Appendix 12 – DDMRP simulation model

The simulation activity uses Microsoft Excel® as the main tool. The demand data from 2013 in form of customer orders has been extracted from the current ERP system by using a self-developed SQL script. The data has been copied into one sheet to represent the reality of 2013. In this sheet the booking date, the material movement (positive or negative) and the resulting stock level are shown. Furthermore, the calculated DDMRP buffer levels (i.e. Green, Yellow, Red Safety and Red Base) and buffer zones (i.e. TOG, TOY and TOR) are shown. The following formulas are used:

$$TOR = Red\ Safety + Red\ Base$$
$$TOY = TOR + Yellow$$
$$TOG = TOY + Green$$

To arrive at the performance indicators (i.e. High Inventory Alert, Low Inventory Alert and Stock out) the following formulas are used:

$$High\ Inventory\ Alert = if(Stock > TOY)\ then\ 1\ else\ 0\ endif;$$
$$Low\ Inventory\ Alert = if(Stock < TOR)\ then\ 1\ else\ 0\ endif;$$
$$Stock\ Out = if(Stock < Red\ Safety)\ then\ 1\ else\ 0\ endif;$$

An extract of the data for the SKU ADSP2 is shown in the following two tables where the first table shows the data from the reality of 2013 and the second the DDMRP simulation results.

Date	Quantity	Stock	Green	Yellow	Red Safety	Red Base	TOG	TOY	TOR	High Inv Alert	Low Inv Alert	Stock out
01.01.13	3282.75	3282.75	655	2082	312	655	3704	3049	967	1	0	0
04.01.13	-3	3279.75	655	2082	312	655	3704	3049	967	1	0	0
07.01.13	-26	3253.75	655	2082	312	655	3704	3049	967	1	0	0
08.01.13	-2	3251.75	655	2082	312	655	3704	3049	967	1	0	0
09.01.13	-1	3250.75	655	2082	312	655	3704	3049	967	1	0	0
10.01.13	-5	3245.75	655	2082	312	655	3704	3049	967	1	0	0
11.01.13	-10	3235.75	655	2082	312	655	3704	3049	967	1	0	0
14.01.13	-1	3234.75	655	2082	312	655	3704	3049	967	1	0	0
16.01.13	-42	3192.75	655	2082	312	655	3704	3049	967	1	0	0
17.01.13	-15	3177.75	655	2082	312	655	3704	3049	967	1	0	0
18.01.13	-2	3175.75	655	2082	312	655	3704	3049	967	1	0	0
21.01.13	-3.622	3172.128	655	2082	312	655	3704	3049	967	1	0	0
22.01.13	-23.2	3148.928	655	2082	312	655	3704	3049	967	1	0	0
24.01.13	-8	3140.928	655	2082	312	655	3704	3049	967	1	0	0
25.01.13	-13	3127.928	655	2082	312	655	3704	3049	967	1	0	0
29.01.13	-0.234	3127.694	655	2082	312	655	3704	3049	967	1	0	0
30.01.13	-4	3123.694	655	2082	312	655	3704	3049	967	1	0	0
06.02.13	-3	3120.694	655	2082	312	655	3704	3049	967	1	0	0
07.02.13	-9	3111.694	655	2082	312	655	3704	3049	967	1	0	0
12.02.13	907	4018.694	655	2082	312	655	3704	3049	967	1	0	0
13.02.13	-8	4010.694	655	2082	312	655	3704	3049	967	1	0	0
14.02.13	-11.018	3999.676	655	2082	312	655	3704	3049	967	1	0	0
15.02.13	-0.048	3999.628	655	2082	312	655	3704	3049	967	1	0	0
21.02.13	-0.083	3999.545	655	2082	312	655	3704	3049	967	1	0	0
25.02.13	-1	3998.545	655	2082	312	655	3704	3049	967	1	0	0
27.02.13	-5	3993.545	655	2082	312	655	3704	3049	967	1	0	0
01.03.13	-3	3990.545	655	2082	312	655	3704	3049	967	1	0	0
04.03.13	-528	3462.545	655	2082	312	655	3704	3049	967	1	0	0
05.03.13	-24	3438.545	655	2082	312	655	3704	3049	967	1	0	0
07.03.13	-19.089	3419.456	655	2082	312	655	3704	3049	967	1	0	0
11.03.13	-6	3413.456	655	2082	312	655	3704	3049	967	1	0	0
12.03.13	-14	3399.456	655	2082	312	655	3704	3049	967	1	0	0
13.03.13	-12.141	3387.315	655	2082	312	655	3704	3049	967	1	0	0
18.03.13	-1	3386.315	655	2082	312	655	3704	3049	967	1	0	0
19.03.13	-2	3384.315	655	2082	312	655	3704	3049	967	1	0	0
20.03.13	-11	3373.315	655	2082	312	655	3704	3049	967	1	0	0
21.03.13	-1927.056	1446.259	655	2082	312	655	3704	3049	967	0	0	0
22.03.13	-6	1440.259	655	2082	312	655	3704	3049	967	0	0	0
25.03.13	-19	1421.259	655	2082	312	655	3704	3049	967	0	0	0
03.04.13	-9	1412.259	655	2082	312	655	3704	3049	967	0	0	0

Date	Quantity	Stock	Green	Yellow	Red Safety	Red Base	TOG	TOY	TOR	High Inv Alert	Low Inv Alert	Stock out
01.01.13	3282.75	3282.75	655	2082	312	655	3704	3049	967	1	0	0
04.01.13	-3	3279.75	655	2082	312	655	3704	3049	967	1	0	0
07.01.13	-26	3253.75	655	2082	312	655	3704	3049	967	1	0	0
08.01.13	-2	3251.75	655	2082	312	655	3704	3049	967	1	0	0
09.01.13	-1	3250.75	655	2082	312	655	3704	3049	967	1	0	0
10.01.13	-5	3245.75	655	2082	312	655	3704	3049	967	1	0	0
11.01.13	-10	3235.75	655	2082	312	655	3704	3049	967	1	0	0
14.01.13	-1	3234.75	655	2082	312	655	3704	3049	967	1	0	0
16.01.13	-42	3192.75	655	2082	312	655	3704	3049	967	1	0	0
17.01.13	-15	3177.75	655	2082	312	655	3704	3049	967	1	0	0
18.01.13	-2	3175.75	655	2082	312	655	3704	3049	967	1	0	0
21.01.13	-3.622	3172.128	655	2082	312	655	3704	3049	967	1	0	0
22.01.13	-23.2	3148.928	655	2082	312	655	3704	3049	967	1	0	0
24.01.13	-8	3140.928	655	2082	312	655	3704	3049	967	1	0	0
25.01.13	-13	3127.928	655	2082	312	655	3704	3049	967	1	0	0
29.01.13	-0.234	3127.694	655	2082	312	655	3704	3049	967	1	0	0
30.01.13	-4	3123.694	655	2082	312	655	3704	3049	967	1	0	0
06.02.13	-3	3120.694	655	2082	312	655	3704	3049	967	1	0	0
07.02.13	-9	3111.694	655	2082	312	655	3704	3049	967	1	0	0
12.02.13	0	3111.694	655	2082	312	655	3704	3049	967	1	0	0
13.02.13	-8	3103.694	655	2082	312	655	3704	3049	967	1	0	0
14.02.13	-11.018	3092.676	655	2082	312	655	3704	3049	967	1	0	0
15.02.13	-0.048	3092.628	655	2082	312	655	3704	3049	967	1	0	0
21.02.13	-0.083	3092.545	655	2082	312	655	3704	3049	967	1	0	0
25.02.13	-1	3091.545	655	2082	312	655	3704	3049	967	1	0	0
27.02.13	-5	3086.545	655	2082	312	655	3704	3049	967	1	0	0
01.03.13	-3	3083.545	655	2082	312	655	3704	3049	967	1	0	0
04.03.13	-528	2555.545	655	2082	312	655	3704	3049	967	0	0	0
05.03.13	-24	2531.545	655	2082	312	655	3704	3049	967	0	0	0
07.03.13	-19.089	2512.456	655	2082	312	655	3704	3049	967	0	0	0
11.03.13	-6	2506.456	655	2082	312	655	3704	3049	967	0	0	0
12.03.13	-14	2492.456	655	2082	312	655	3704	3049	967	0	0	0
13.03.13	-12.141	2480.315	655	2082	312	655	3704	3049	967	0	0	0
18.03.13	-1	2479.315	655	2082	312	655	3704	3049	967	0	0	0
19.03.13	-2	2477.315	655	2082	312	655	3704	3049	967	0	0	0
20.03.13	-11	2466.315	655	2082	312	655	3704	3049	967	0	0	0
21.03.13	-1927.056	539.259	655	2082	312	655	3704	3049	967	0	1	0
22.03.13	-6	533.259	655	2082	312	655	3704	3049	967	0	1	0
25.03.13	-19	514.259	655	2082	312	655	3704	3049	967	0	1	0
03.04.13	3000	3514.259	655	2082	312	655	3704	3049	967	1	0	0

Before beginning the simulation, the data representing the reality of 2013 has been copied and production decisions have been eliminated by changing the original value to zero (see the grey cells in the previous two tables).

The simulation rule was to consider only two weeks of demand visibility and to aim for productions somewhere in the middle of the red buffer that are able to fill up the buffer aiming for the green zone. Such production decisions were inserted into the data accordingly (see blue cell in the last table).

The figure of average stock was calculated on the basis the stock figures for the reality of 2013 and the simulation results by using the following formula:

$$avg\ stock = \frac{1}{n} * \sum_{i=0}^{n} x_i = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

n: stock figure count

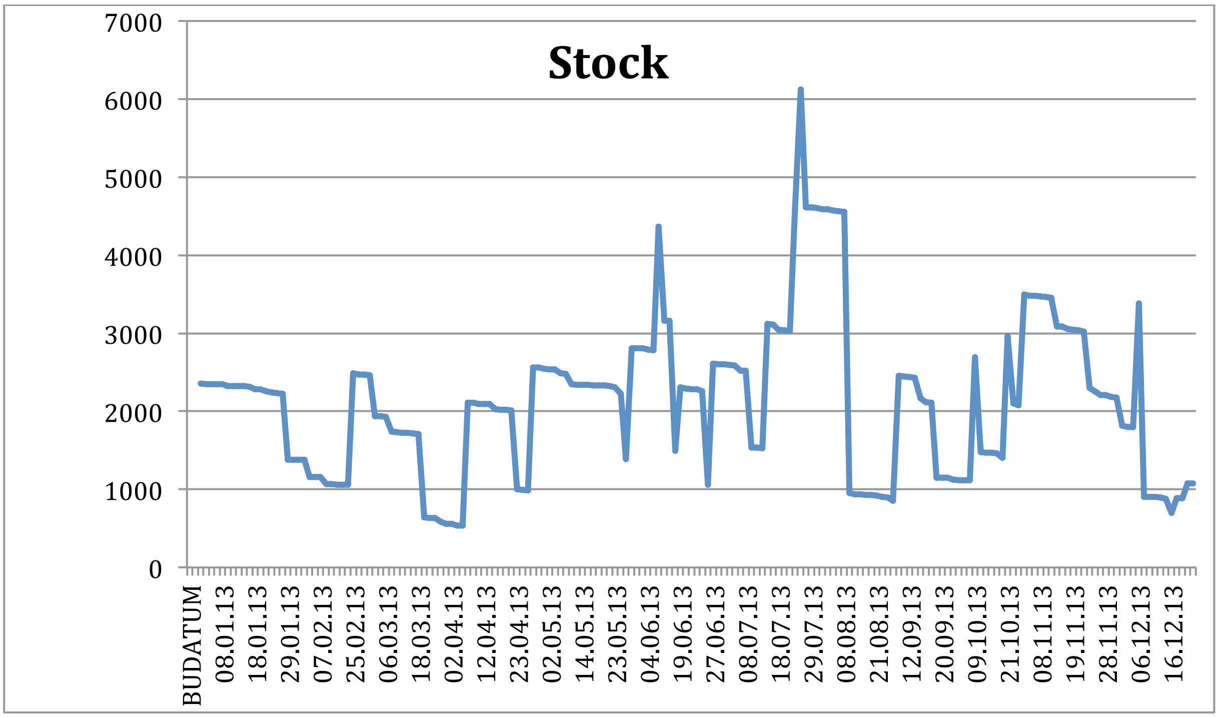
x: individual stock figure

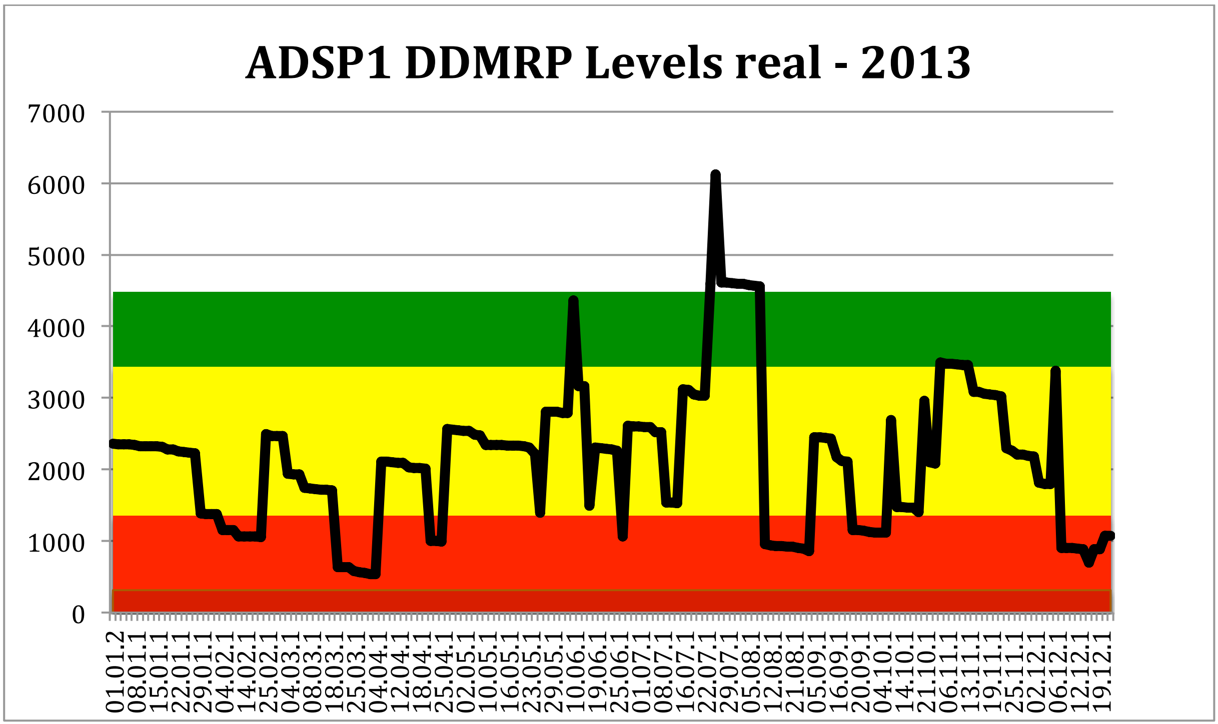
The graphical representations of the simulation results are shown in Appendix 15.

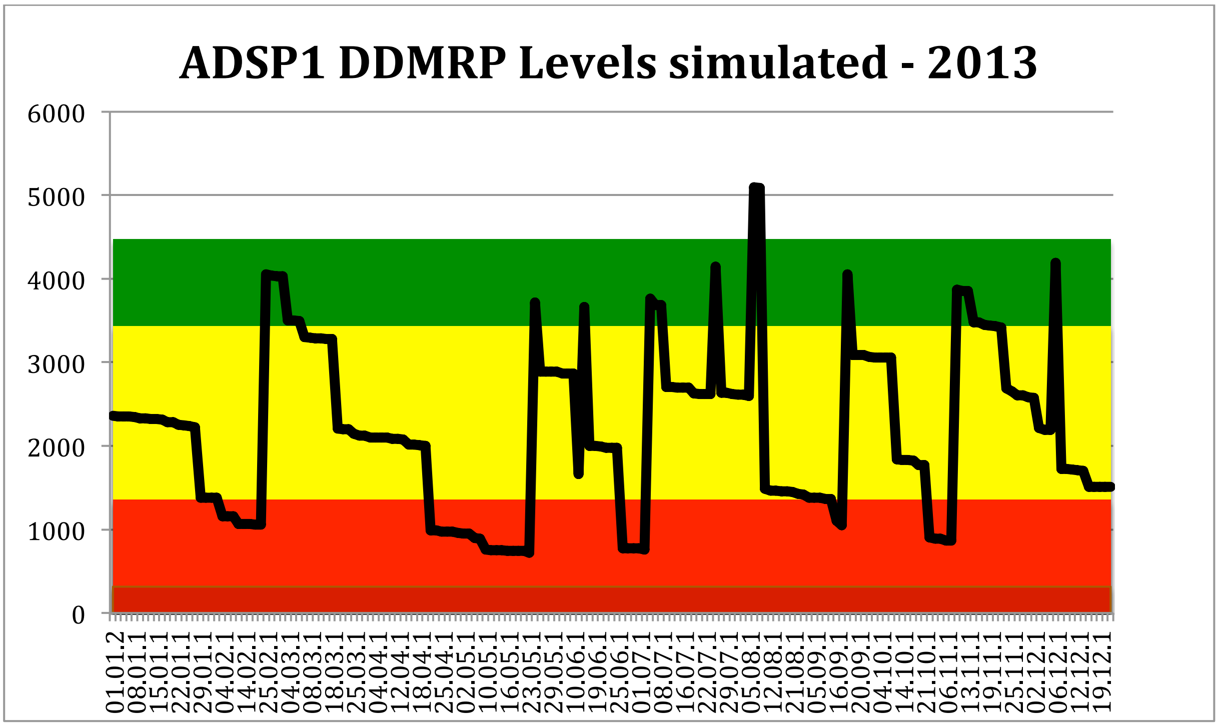
Appendix 13 – DDMRP simulation

The preceding appendices have provided the ground for the simulation based on the ERP data from 2013. For each SKU the real stock levels are shown. Next, these real stock levels are integrated into the DDMRP buffer logic to show its performance. Finally, the DDMRP decision-making simulation by relating decision only to buffer levels is applied.

ADSP1 1KG

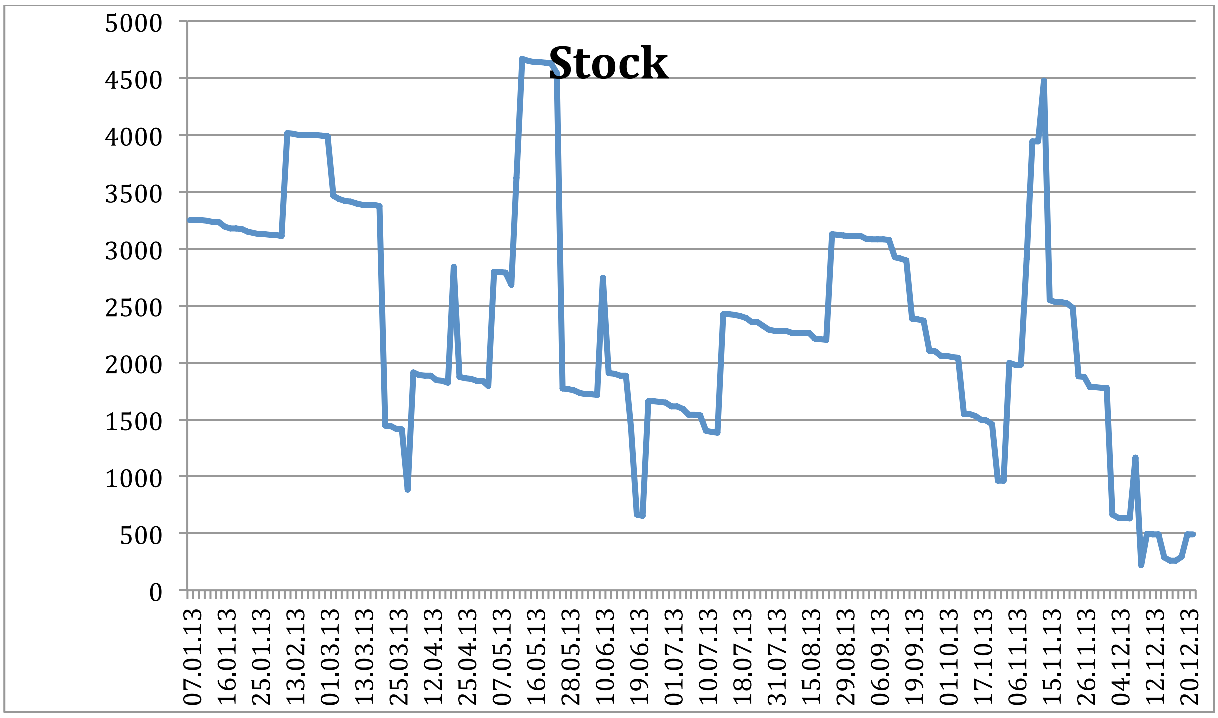


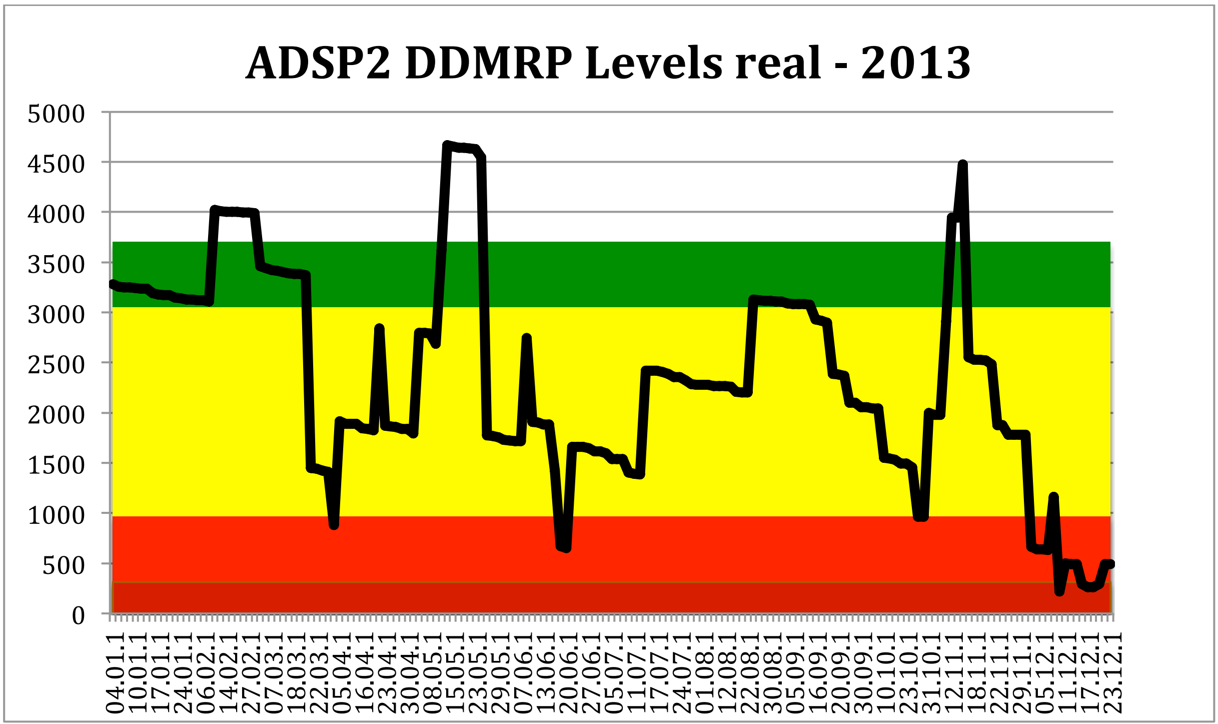


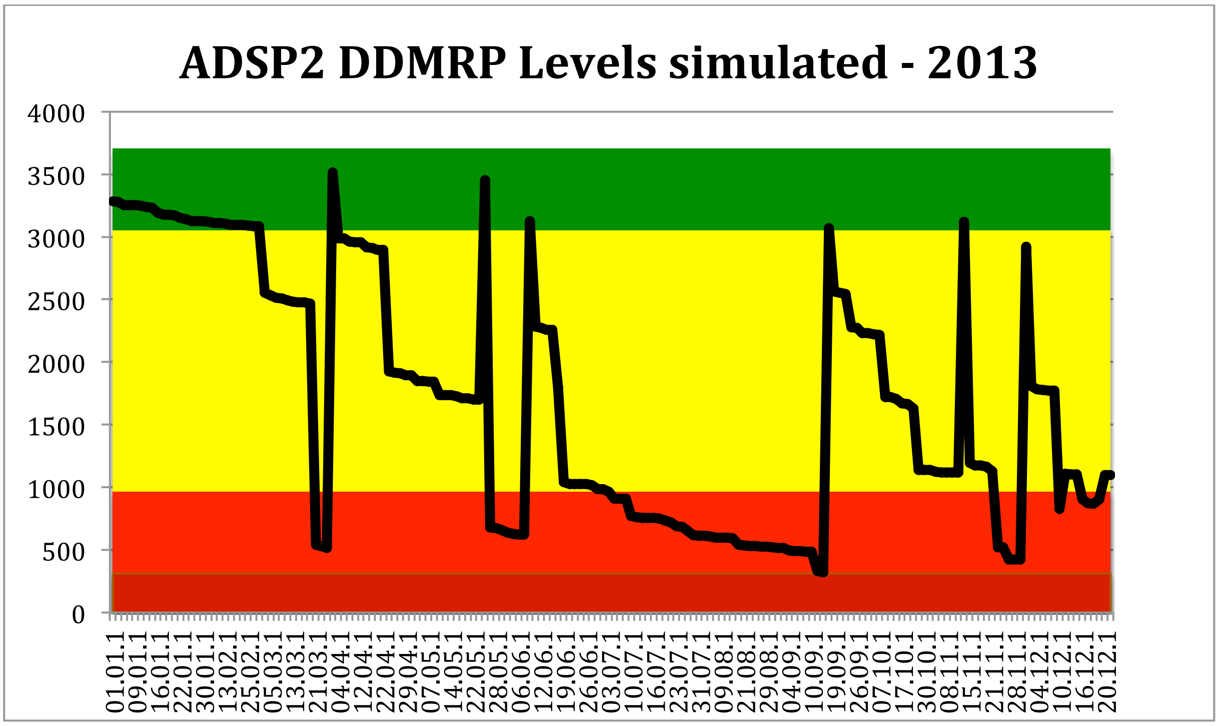


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	185	17	46	0	2130
Simulation	185	24	39	0	2181

ADSP2 1KG

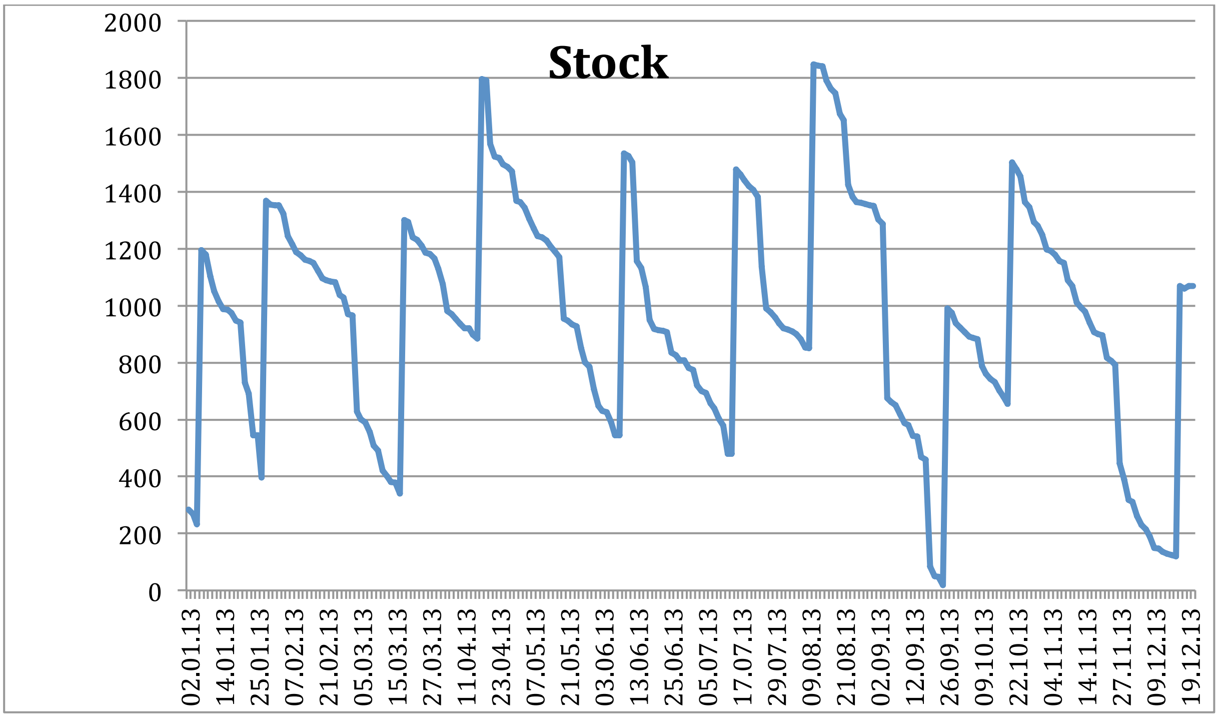

Stock
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
07.01.13
16.01.13
25.01.13
13.02.13
01.03.13
13.03.13
25.03.13
12.04.13
25.04.13
07.05.13
16.05.13
28.05.13
10.06.13
19.06.13
01.07.13
10.07.13
18.07.13
31.07.13
15.08.13
29.08.13
06.09.13
19.09.13
01.10.13
17.10.13
06.11.13
15.11.13
26.11.13
04.12.13
12.12.13
20.12.13

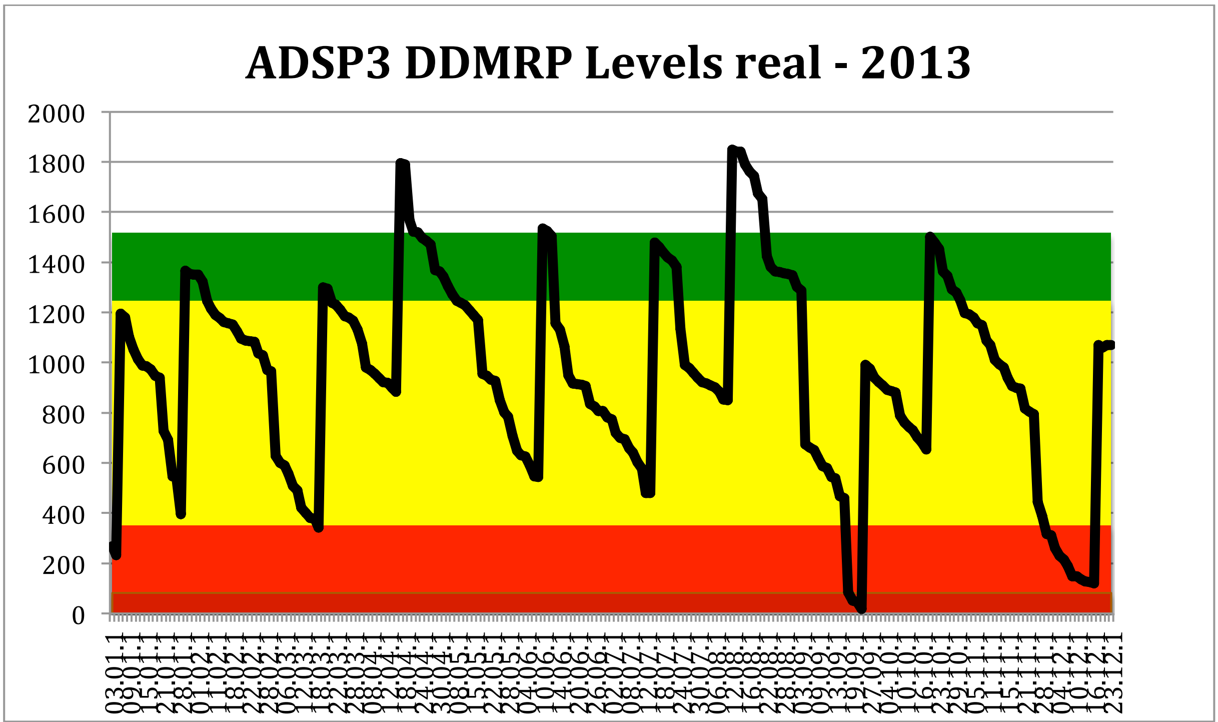

ADSP2 DDMRP Levels real - 2013
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0

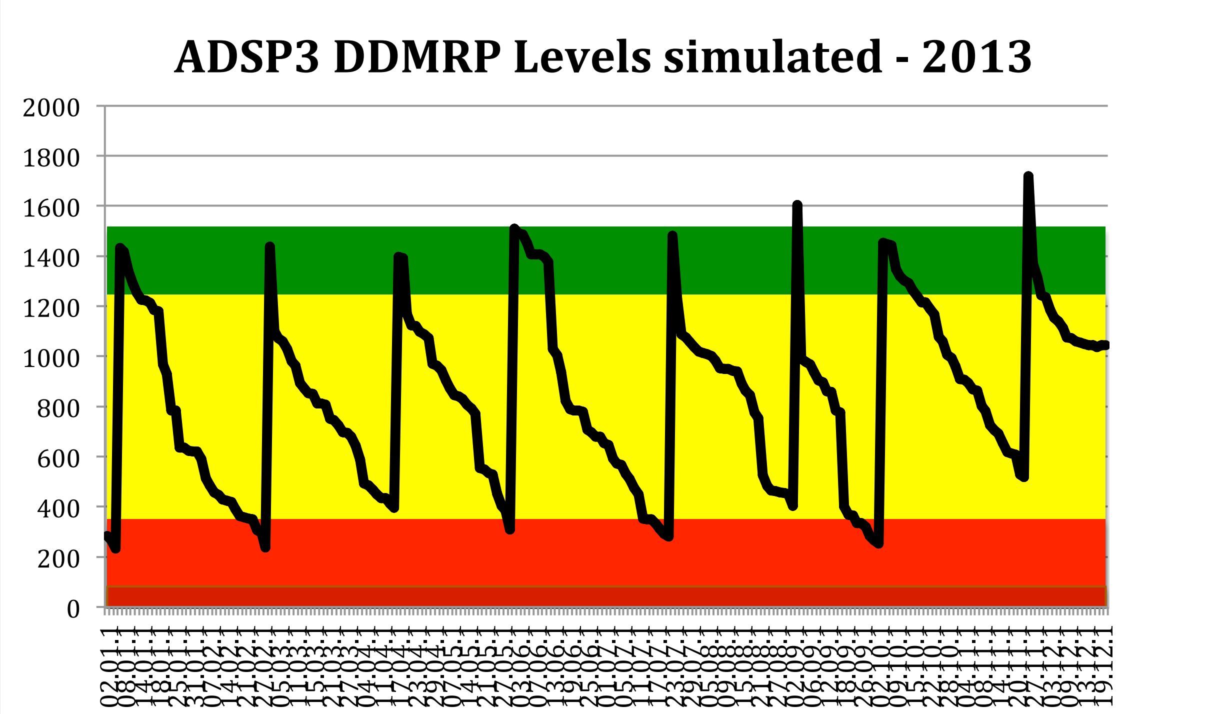


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	180	58	19	5	2354
Simulation	180	32	59	0	1691

ADSP3 1L

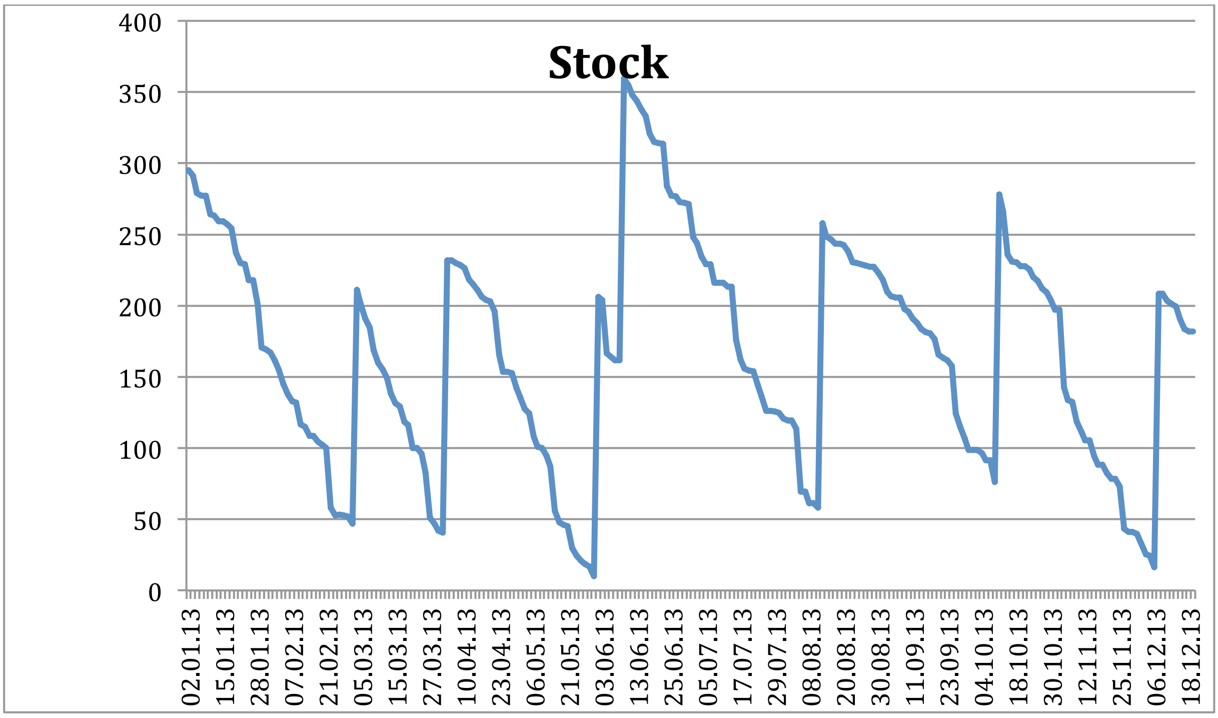

Stock
2000
1800
1600
1400
1200
1000
800
600
400
200
0
02.01.13
14.01.13
25.01.13
07.02.13
21.02.13
05.03.13
15.03.13
27.03.13
11.04.13
23.04.13
07.05.13
21.05.13
03.06.13
13.06.13
25.06.13
05.07.13
17.07.13
29.07.13
09.08.13
21.08.13
02.09.13
12.09.13
26.09.13
09.10.13
22.10.13
04.11.13
14.11.13
27.11.13
09.12.13
19.12.13

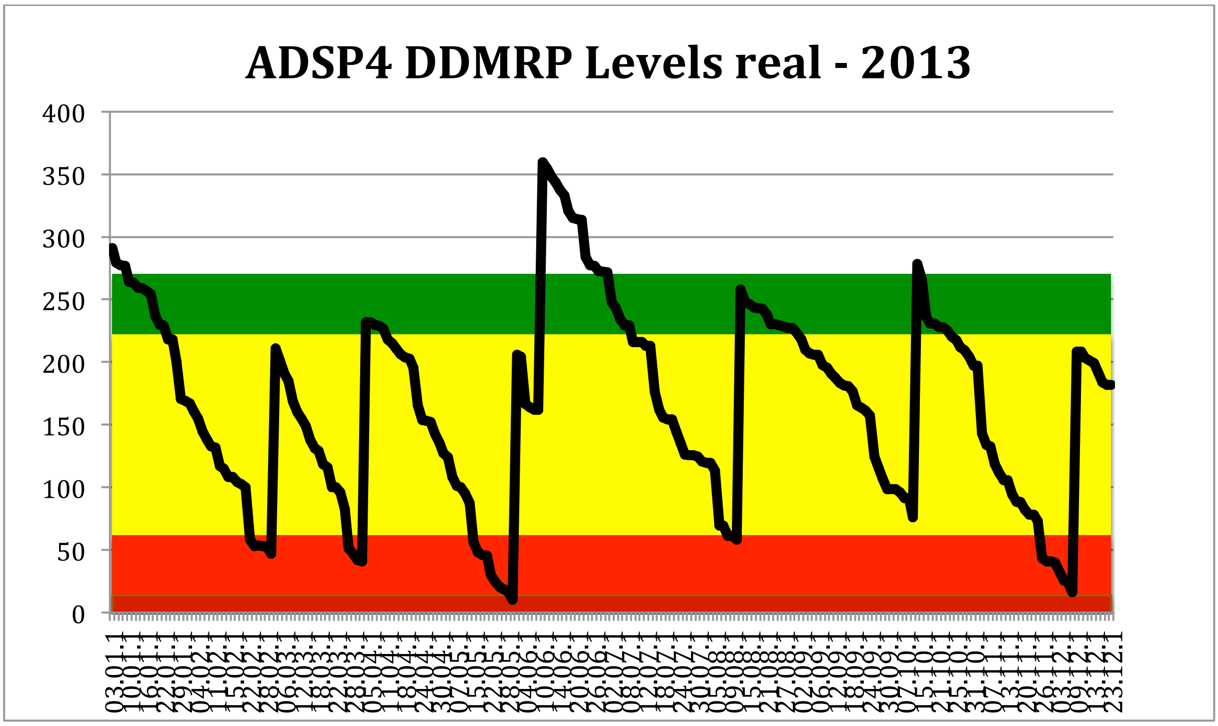

ADSP3 DDMRP Levels real - 2013
2000
1800
1600
1400
1200
1000
800
600
400
200
0

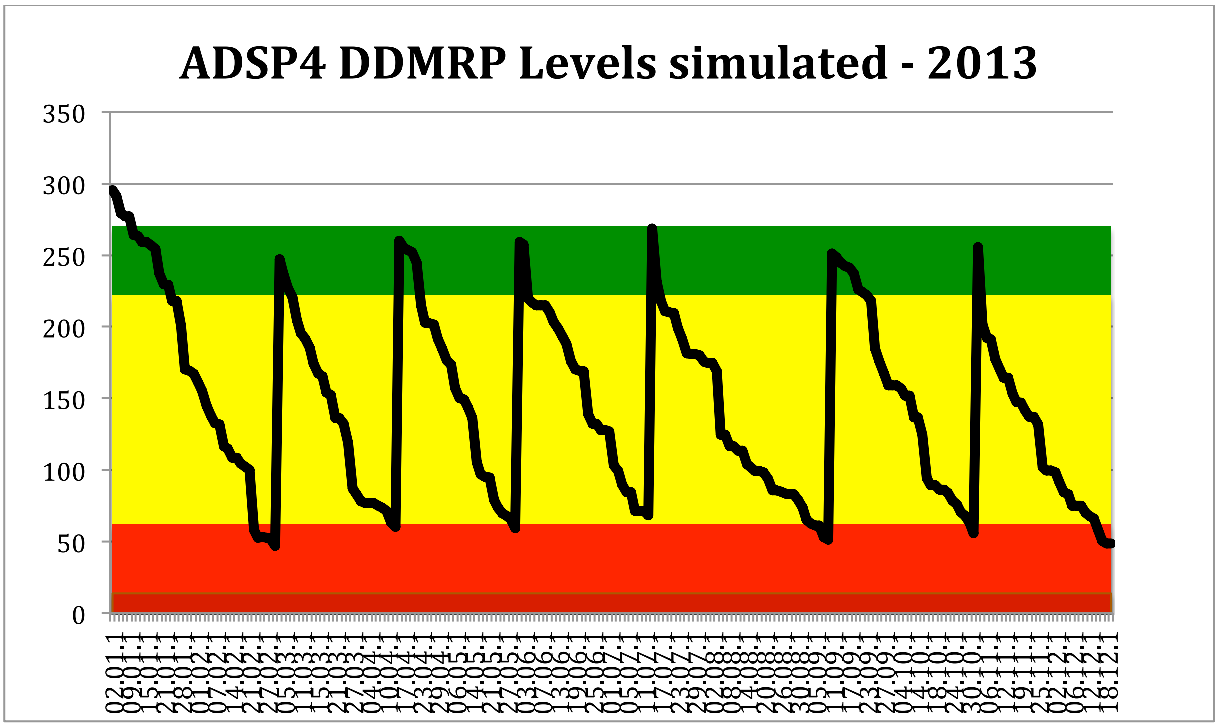


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	237	54	21	3	952
Simulation	237	30	18	0	833

ADSP4 5L

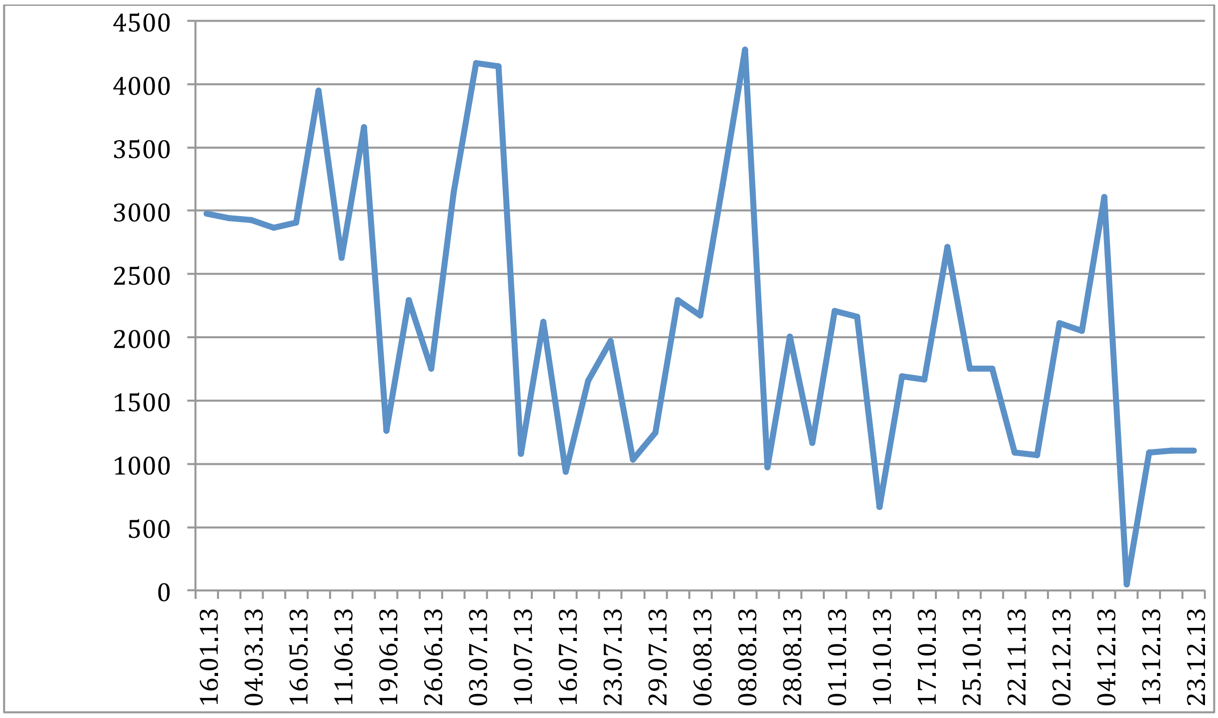

Stock
400
350
300
250
200
150
100
50
0
02.01.13
15.01.13
28.01.13
07.02.13
21.02.13
05.03.13
15.03.13
27.03.13
10.04.13
23.04.13
06.05.13
21.05.13
03.06.13
13.06.13
25.06.13
05.07.13
17.07.13
29.07.13
08.08.13
20.08.13
30.08.13
11.09.13
23.09.13
04.10.13
18.10.13
30.10.13
12.11.13
25.11.13
06.12.13
18.12.13

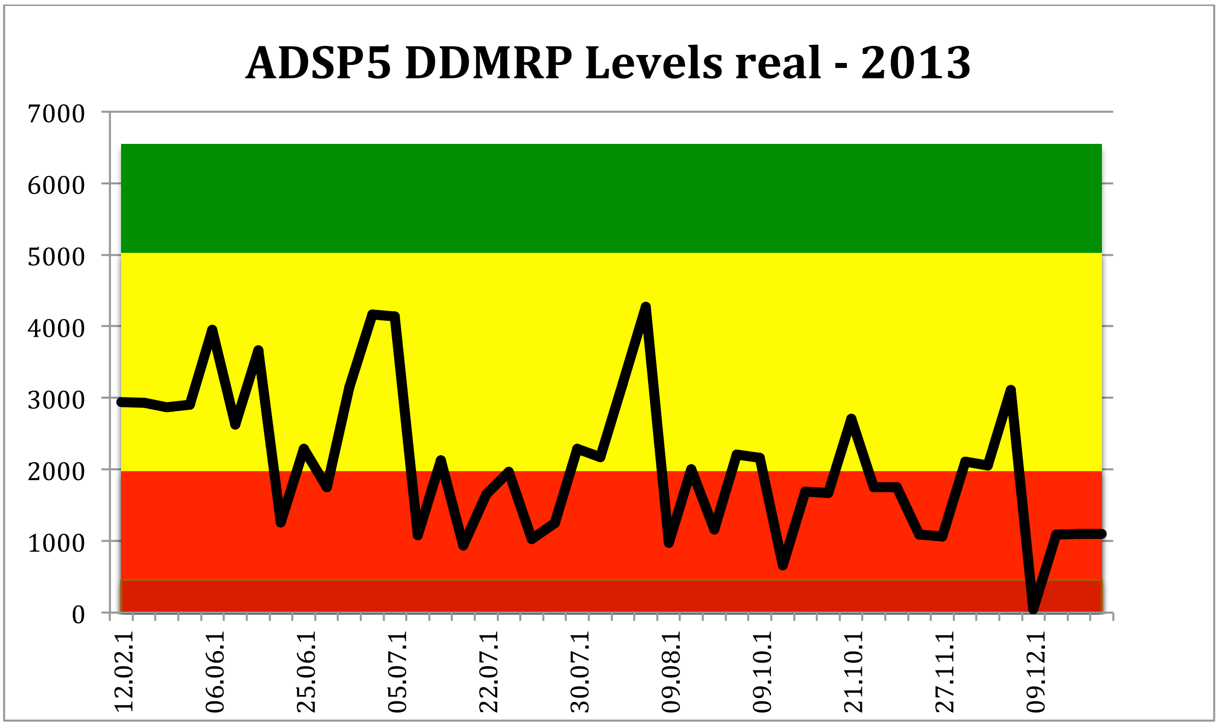

ADSP4 DDMRP Levels real - 2013
400
350
300
250
200
150
100
50
0

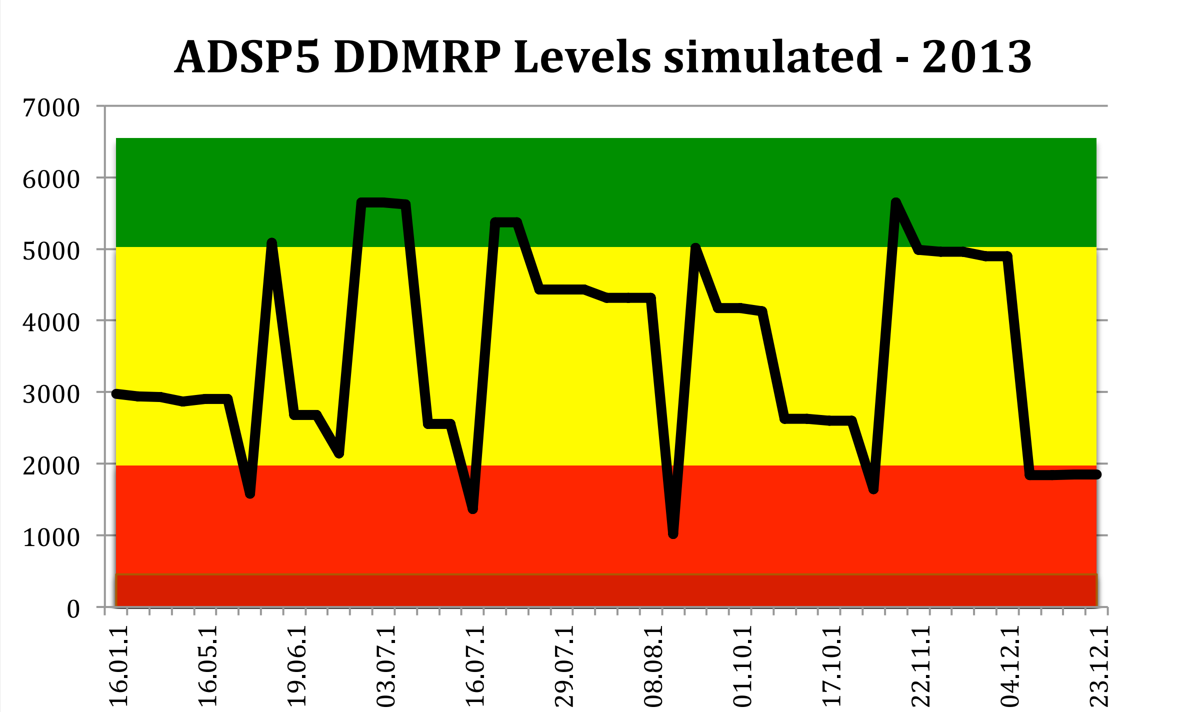


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	237	63	31	1	167
Simulation	237	36	17	0	147

ADSP5 1KG

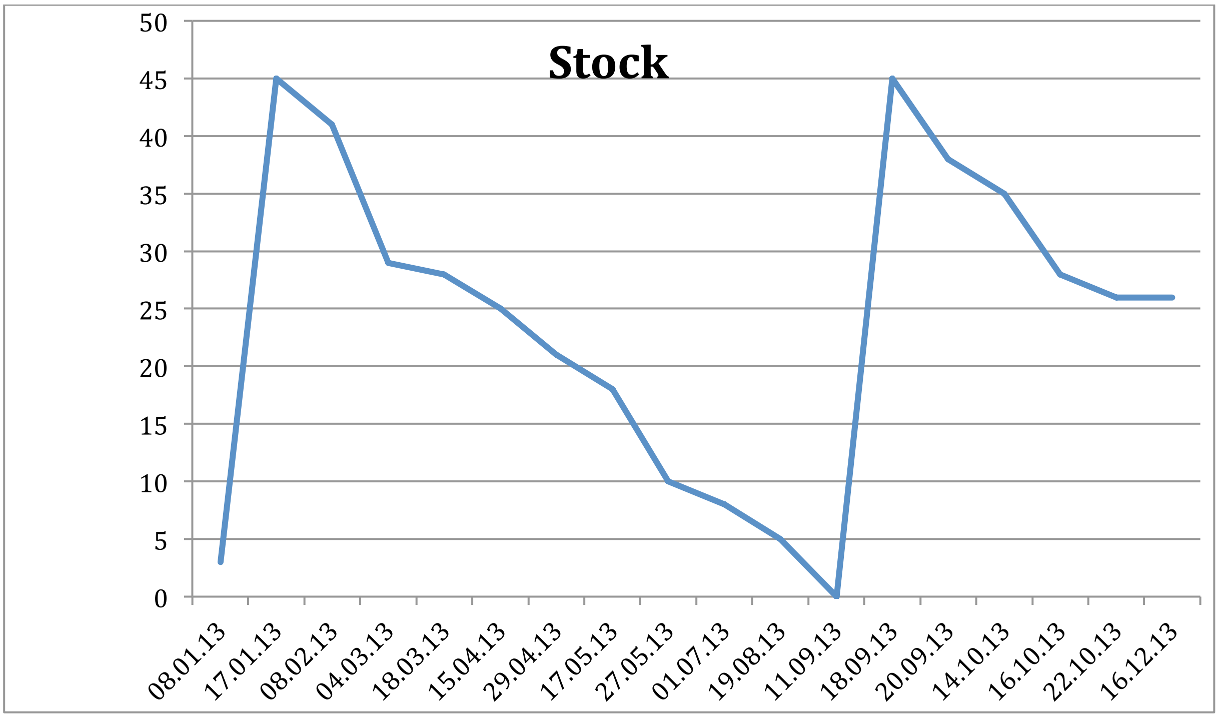

4500
4000
3500
3000
2500
2000
1500
1000
500
0
16.01.13
04.03.13
16.05.13
11.06.13
19.06.13
26.06.13
03.07.13
10.07.13
16.07.13
23.07.13
29.07.13
06.08.13
08.08.13
28.08.13
01.10.13
10.10.13
17.10.13
25.10.13
22.11.13
02.12.13
04.12.13
13.12.13
23.12.13

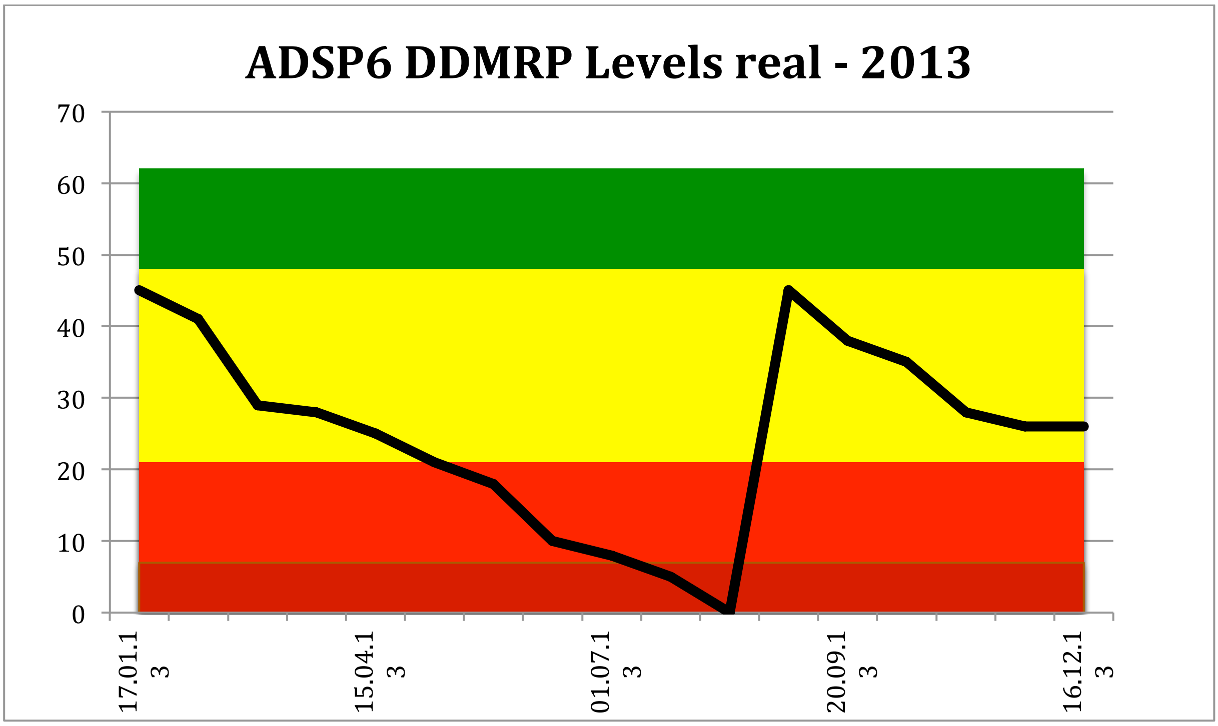

ADSP5 DDMRP Levels real - 2013
7000
6000
5000
4000
3000
2000
1000
0
12.02.1
06.06.1
25.06.1
05.07.1
22.07.1
30.07.1
09.08.1
09.10.1
21.10.1
27.11.1
09.12.1

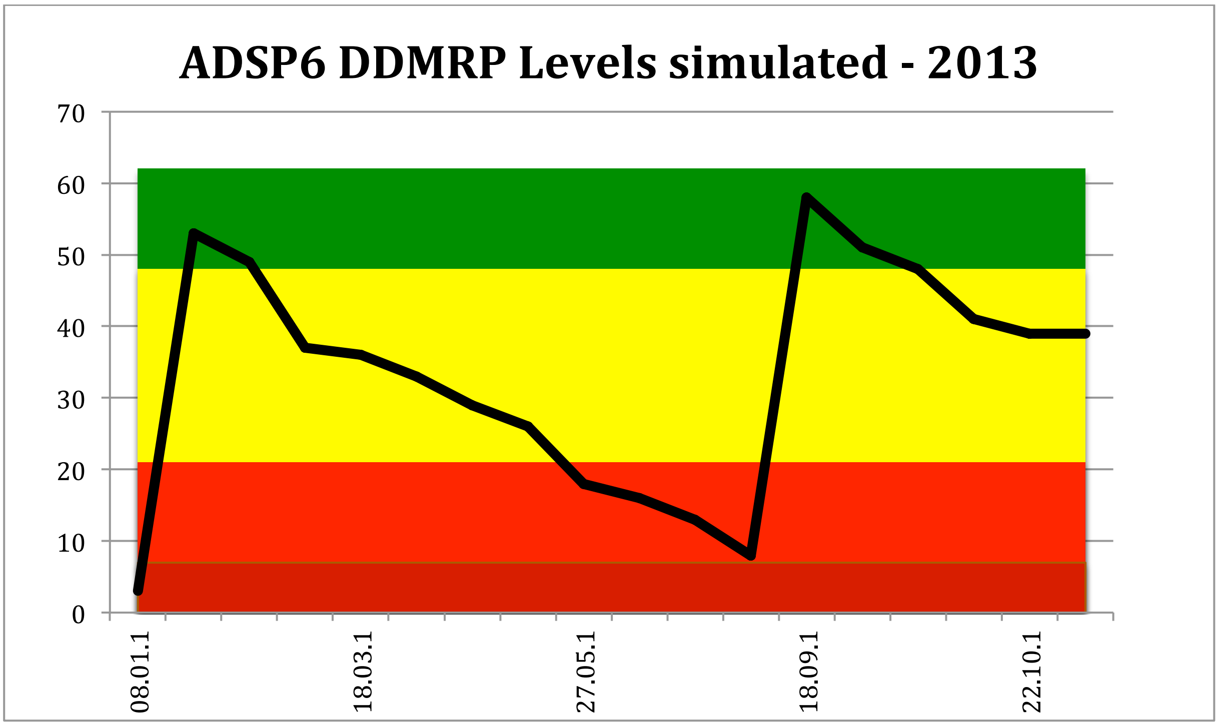


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	48	0	21	1	2133
Simulation	48	7	8	0	3554

ADSP6 1L

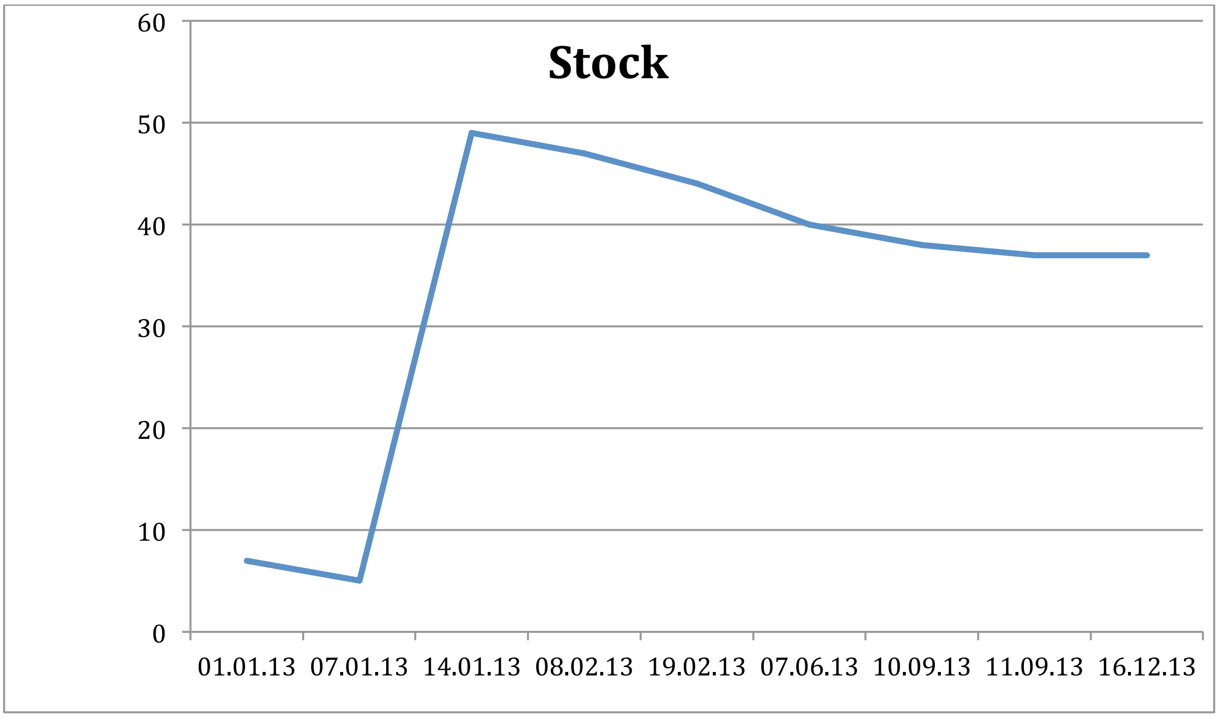

Stock
50
45
40
35
30
25
20
15
10
5
0
08.01.13
17.01.13
08.02.13
04.03.13
18.03.13
15.04.13
29.04.13
17.05.13
27.05.13
01.07.13
19.08.13
11.09.13
18.09.13
20.09.13
14.10.13
16.10.13
22.10.13
16.12.13

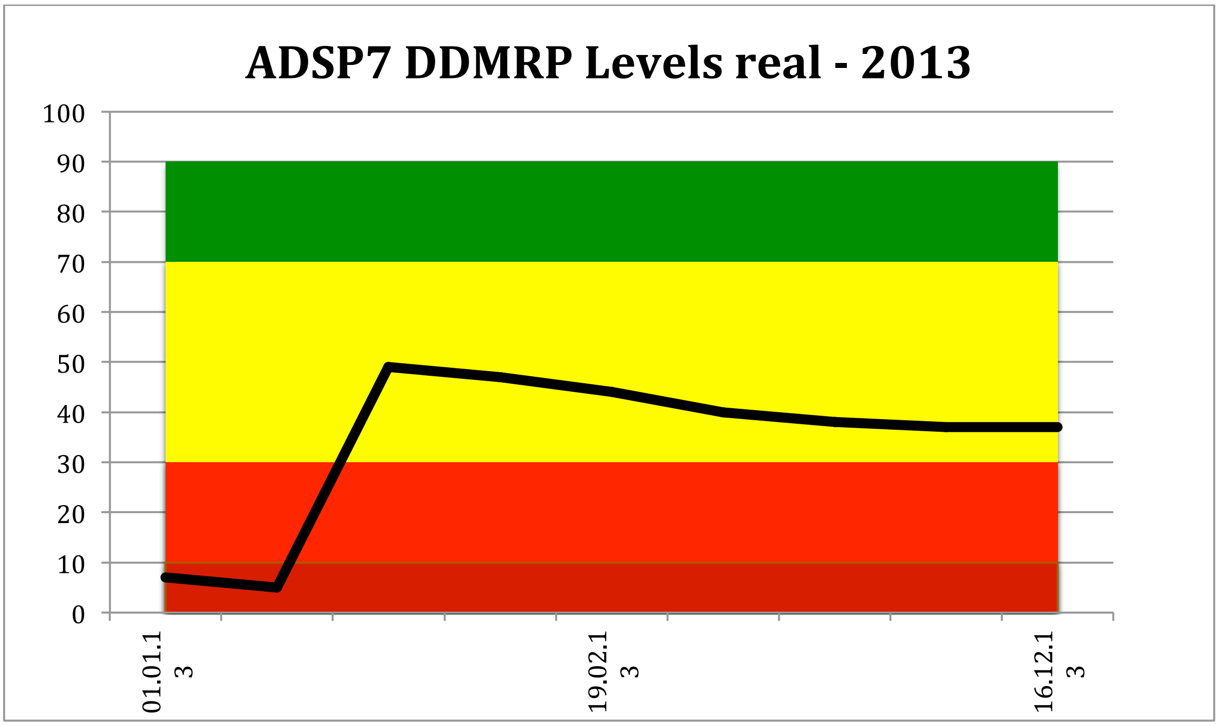

ADSP6 DDMRP Levels real - 2013
70
60
50
40
30
20
10
0
17.01.13
15.04.13
01.07.13
20.09.13
16.12.13

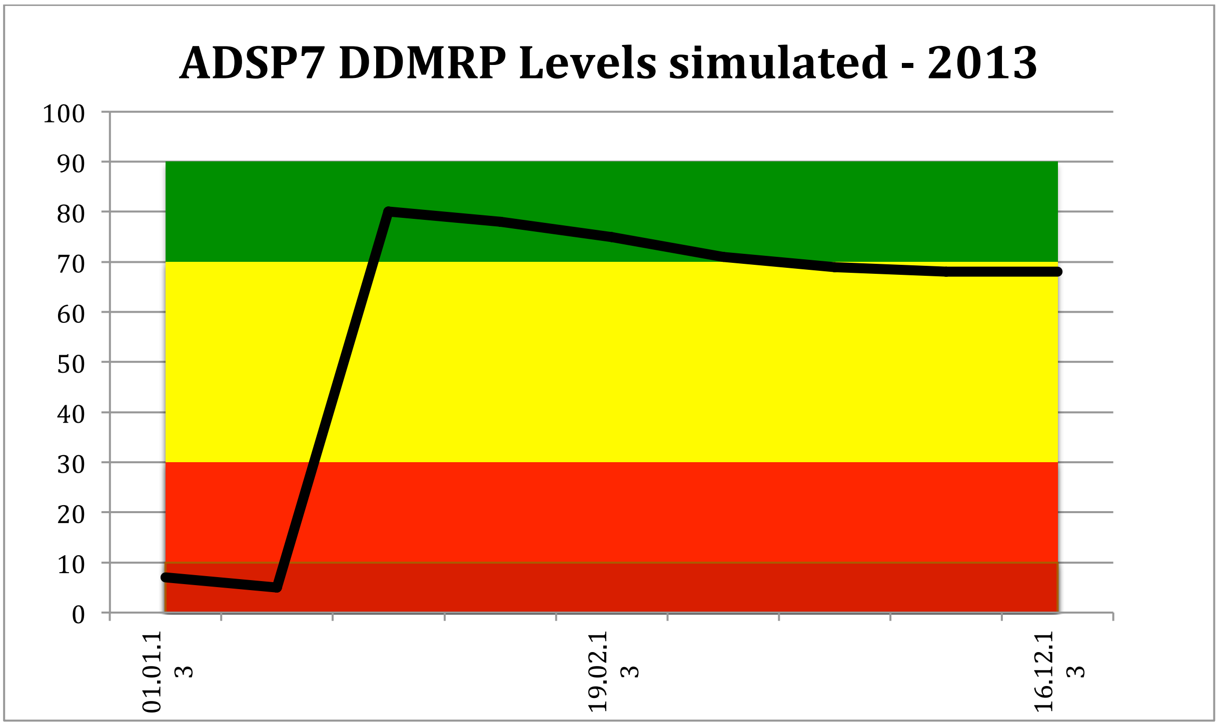


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	21	0	7	4	23
Simulation	21	4	6	2	32

ADSP7 1L

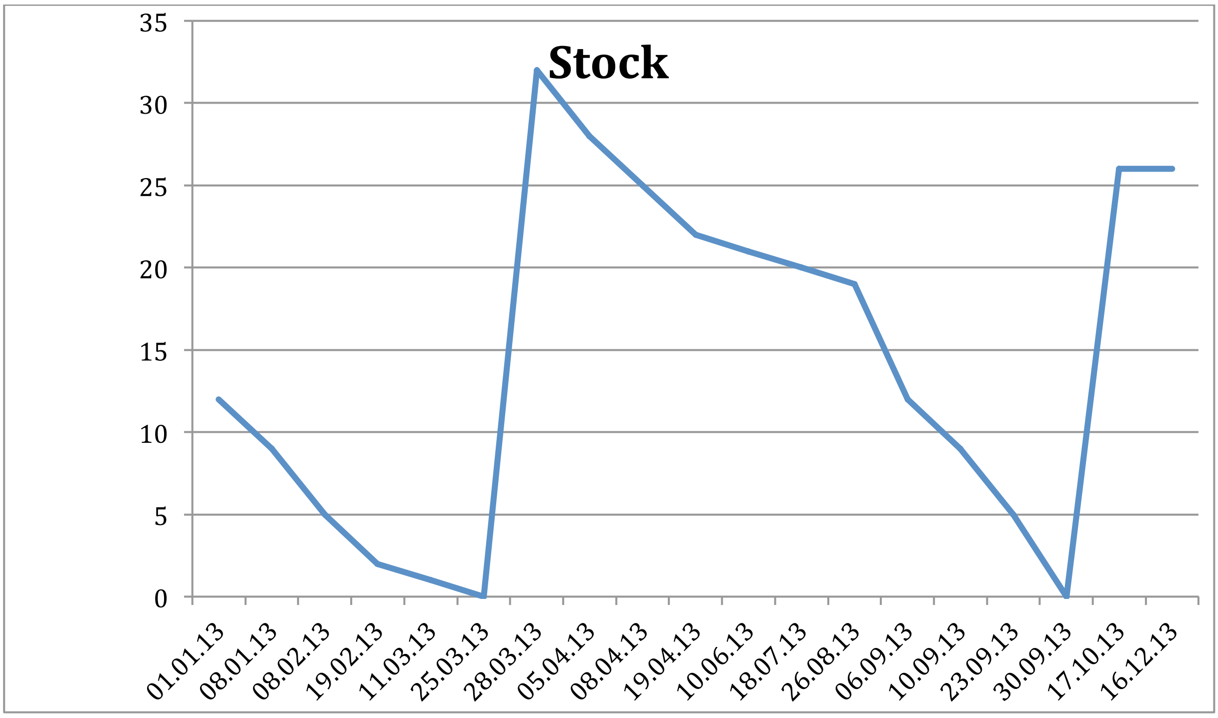

Stock
60
50
40
30
20
10
0
01.01.13
07.01.13
14.01.13
08.02.13
19.02.13
07.06.13
10.09.13
11.09.13
16.12.13

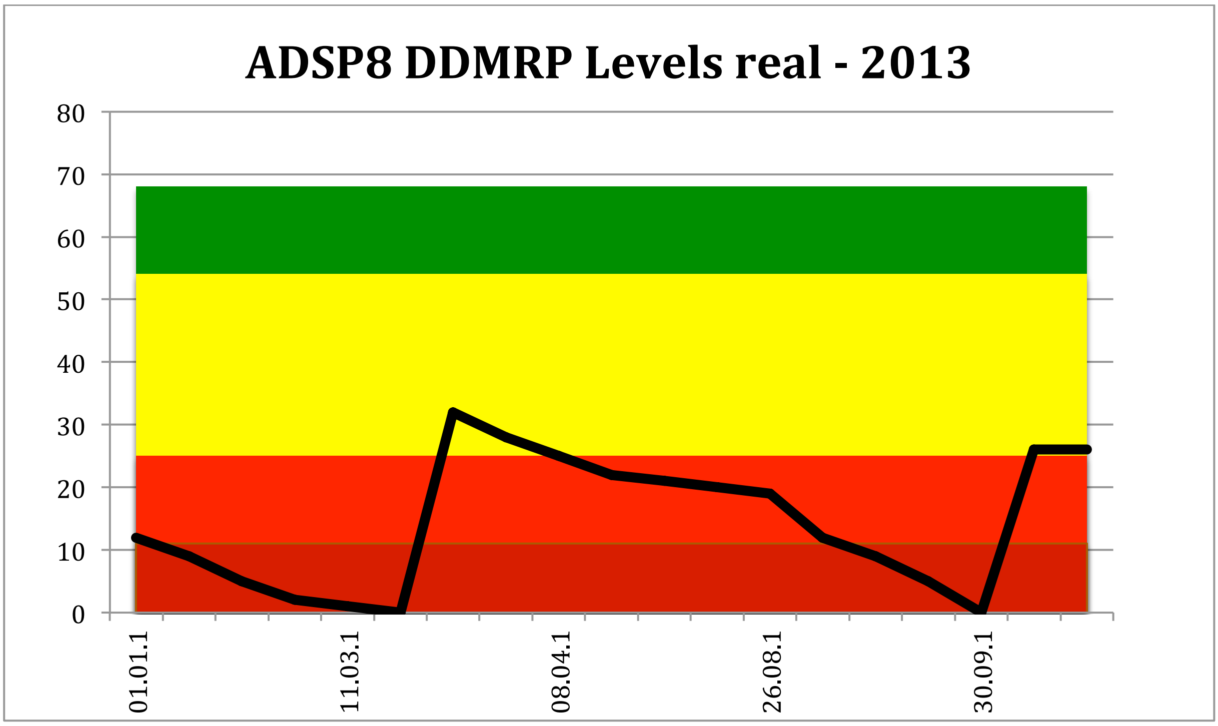

ADSP7 DDMRP Levels real - 2013
100
90
80
70
60
50
40
30
20
10
0
01.01.13
19.02.13
16.12.13

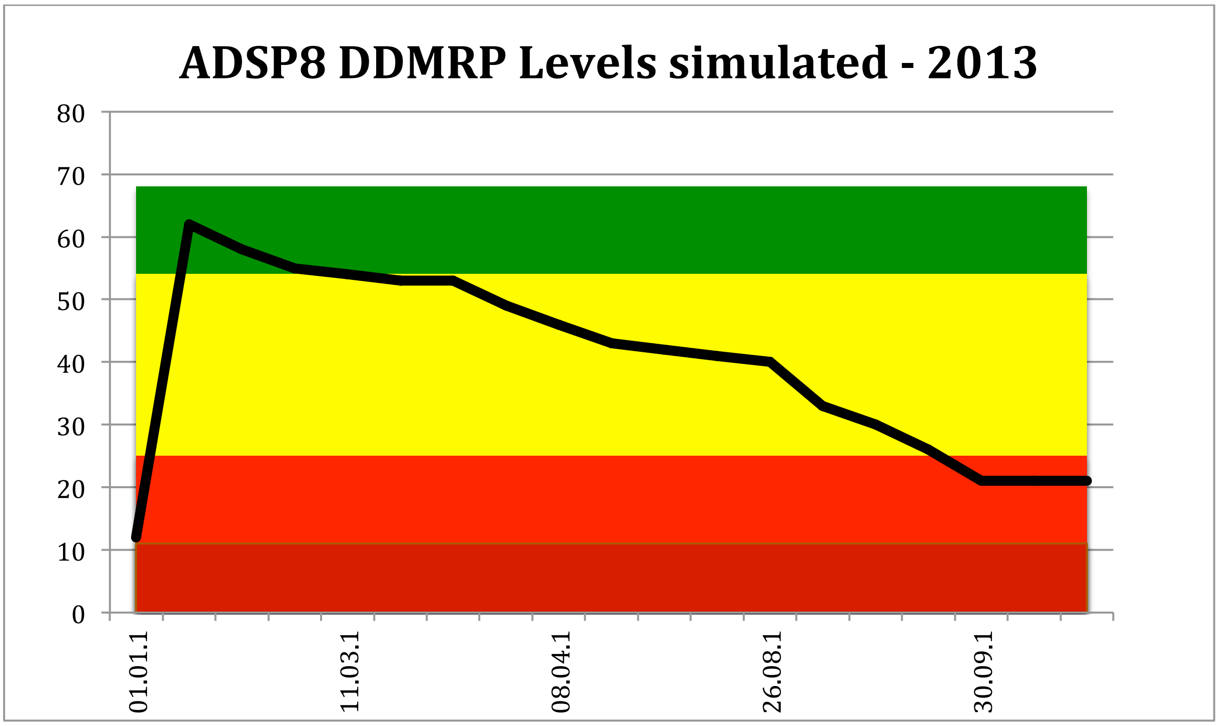


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	11	0	2	2	34
Simulation	11	4	2	2	58

ADSP8 1L

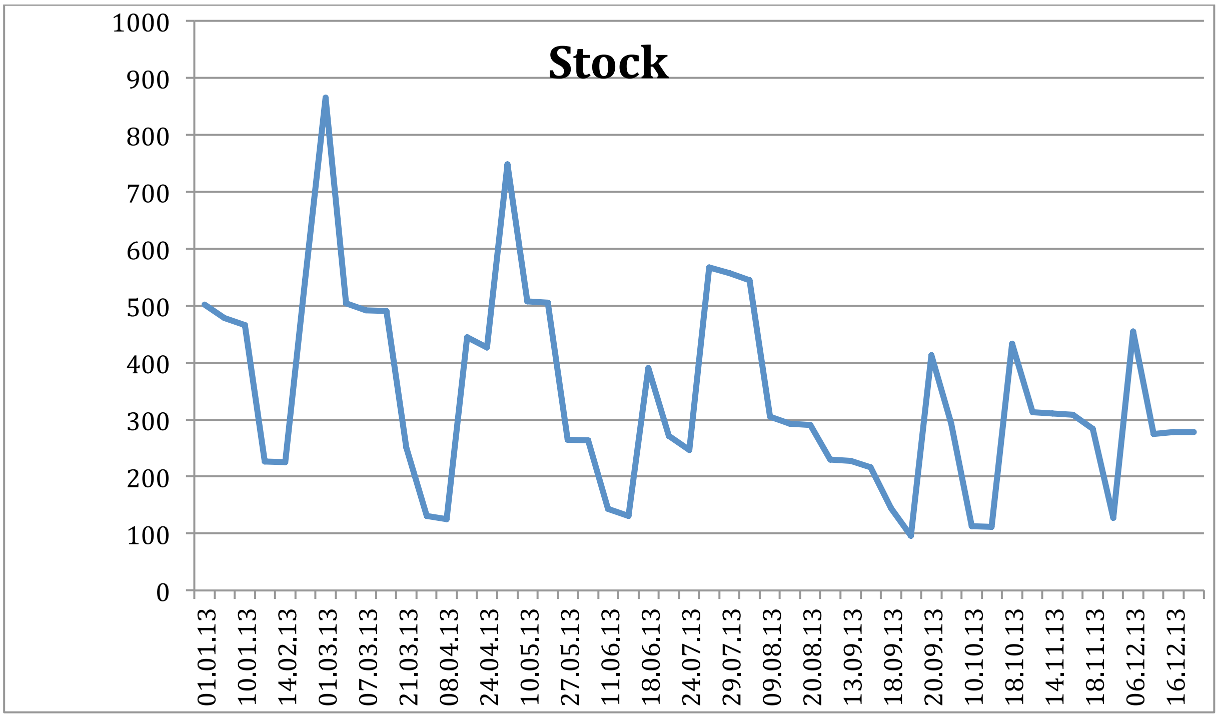

Stock
35
30
25
20
15
10
5
0
01.01.13
08.01.13
08.02.13
19.02.13
11.03.13
25.03.13
28.03.13
05.04.13
08.04.13
19.04.13
10.06.13
18.07.13
26.08.13
06.09.13
10.09.13
23.09.13
30.09.13
17.10.13
16.12.13

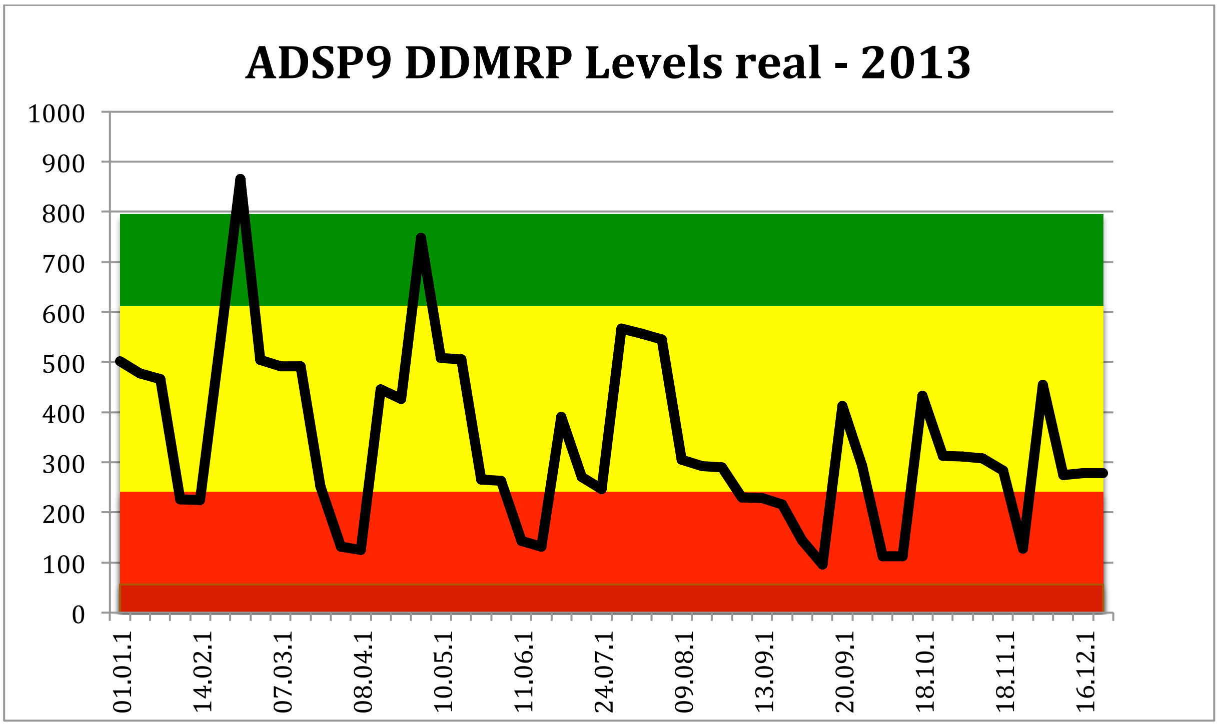

ADSP8 DDMRP Levels real - 2013
80
70
60
50
40
30
20
10
0
01.01.1
11.03.1
08.04.1
26.08.1
30.09.1

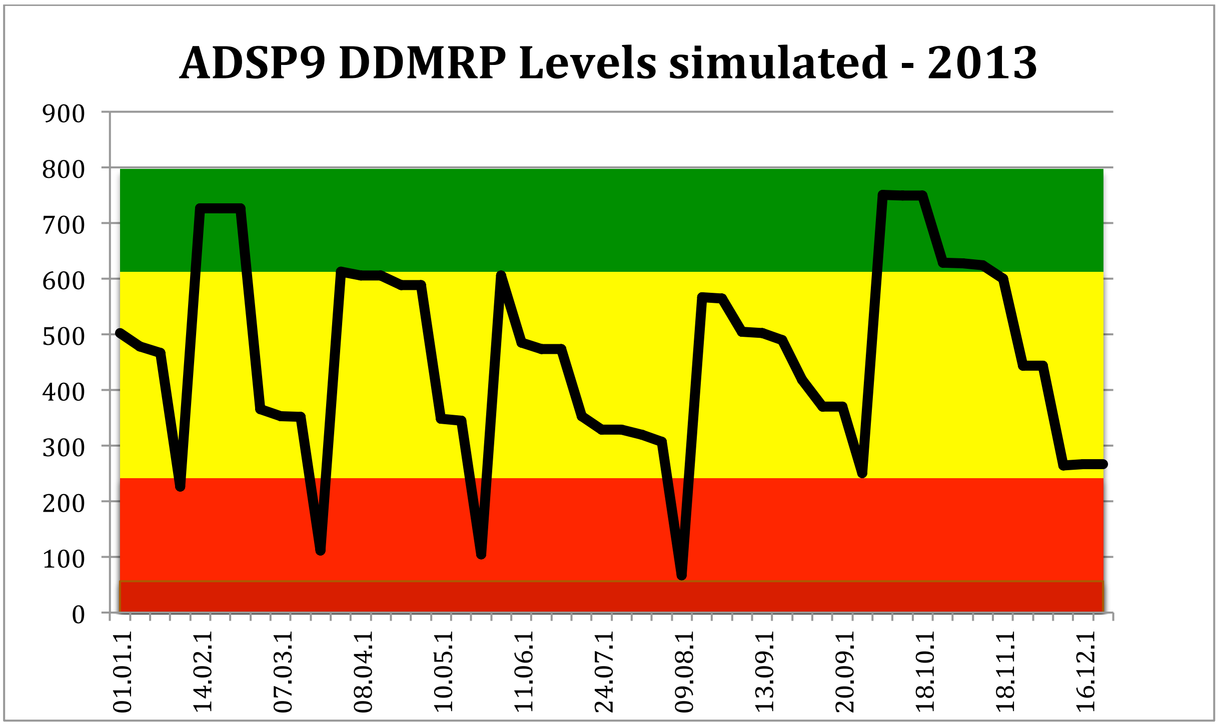


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	21	0	14	8	14
Simulation	21	3	4	0	40

ADSP9 1L

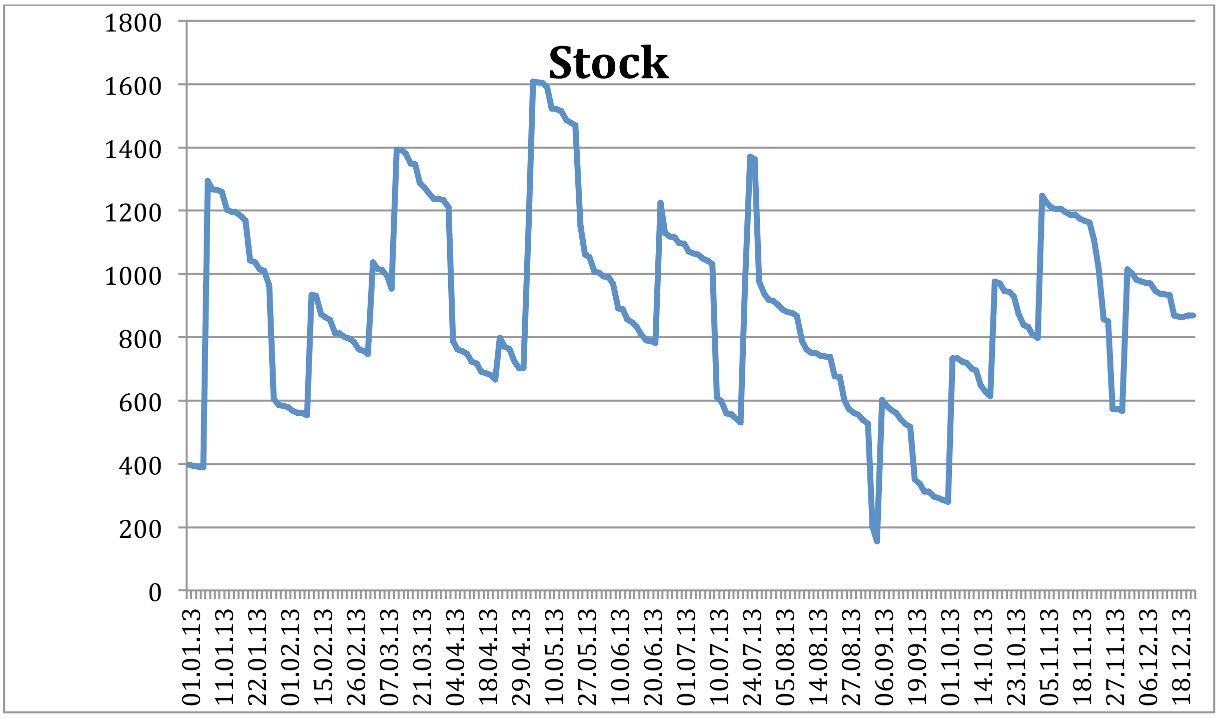

Stock
1000
900
800
700
600
500
400
300
200
100
0
01.01.13
10.01.13
14.02.13
01.03.13
07.03.13
21.03.13
08.04.13
24.04.13
10.05.13
27.05.13
11.06.13
18.06.13
24.07.13
29.07.13
09.08.13
20.08.13
13.09.13
18.09.13
20.09.13
10.10.13
18.10.13
14.11.13
18.11.13
06.12.13
16.12.13

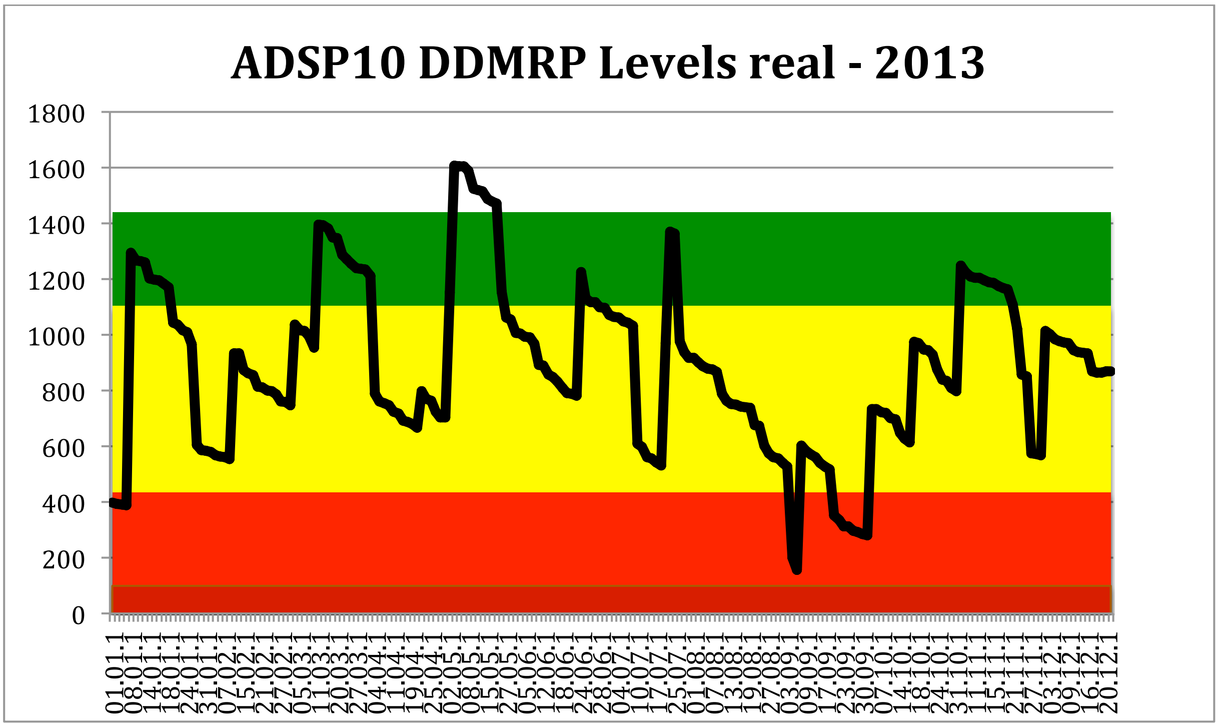

ADSP9 DDMRP Levels real - 2013
1000
900
800
700
600
500
400
300
200
100
0
01.01.1
14.02.1
07.03.1
08.04.1
10.05.1
11.06.1
24.07.1
09.08.1
13.09.1
20.09.1
18.10.1
18.11.1
16.12.1

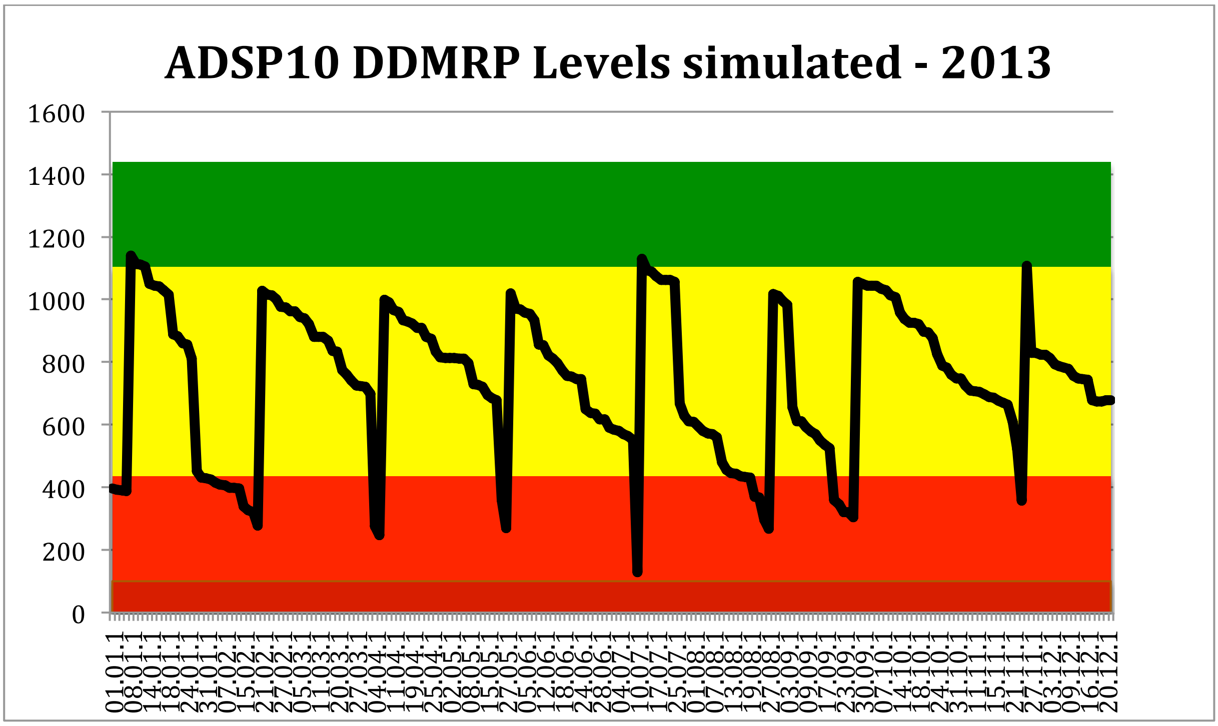


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	52	2	14	0	339
Simulation	52	10	4	0	460

ADSP10 800G

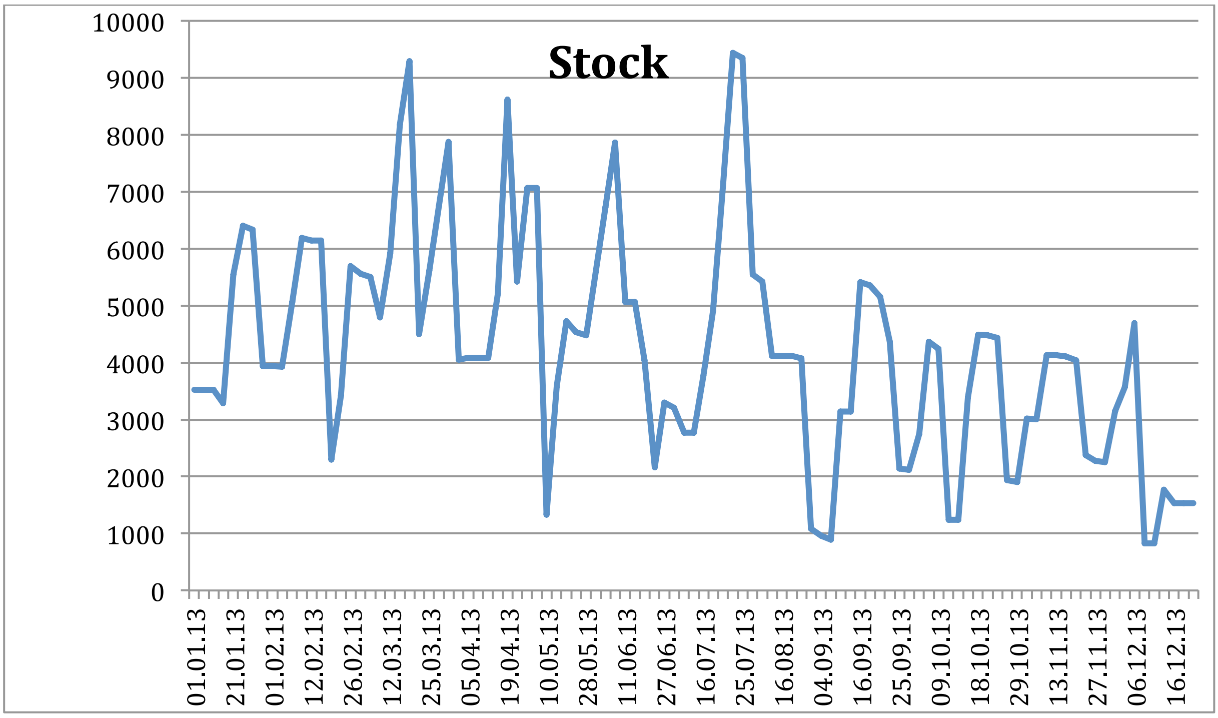

Stock
1800
1600
1400
1200
1000
800
600
400
200
0
01.01.13
11.01.13
22.01.13
01.02.13
15.02.13
26.02.13
07.03.13
21.03.13
04.04.13
18.04.13
29.04.13
10.05.13
27.05.13
10.06.13
20.06.13
01.07.13
10.07.13
24.07.13
05.08.13
14.08.13
27.08.13
06.09.13
19.09.13
01.10.13
14.10.13
23.10.13
05.11.13
18.11.13
27.11.13
06.12.13
18.12.13

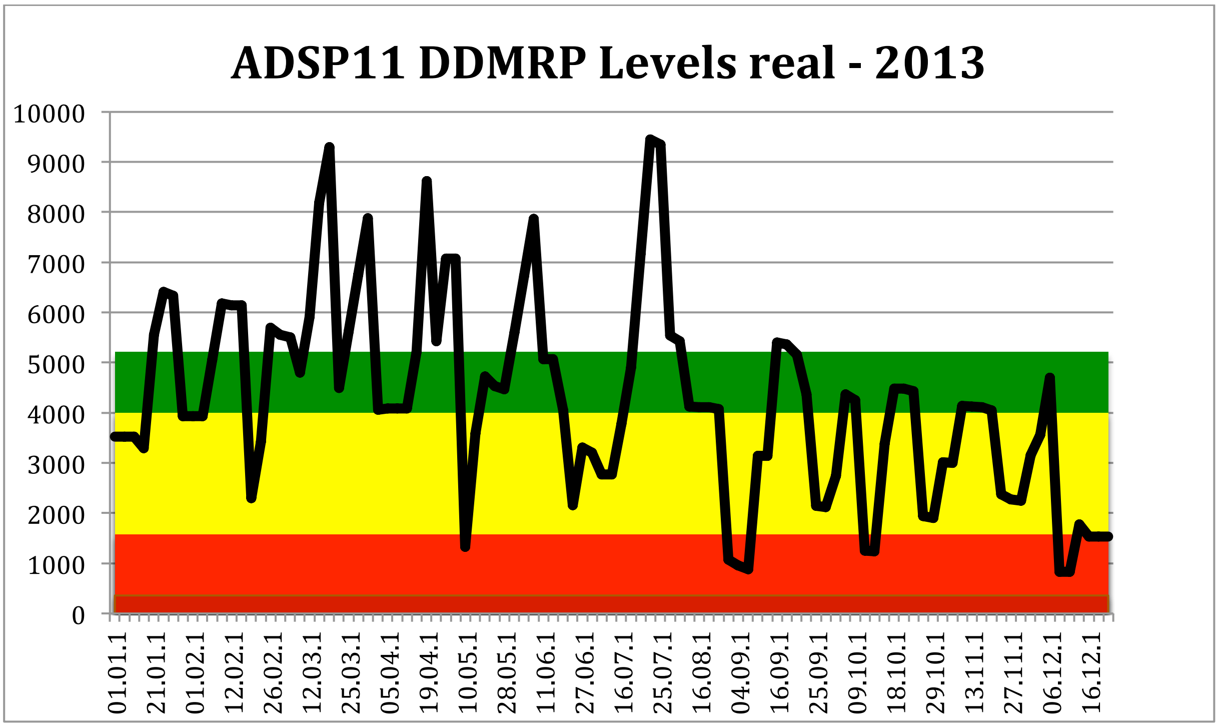

ADSP10 DDMRP Levels real - 2013
1800
1600
1400
1200
1000
800
600
400
200
0

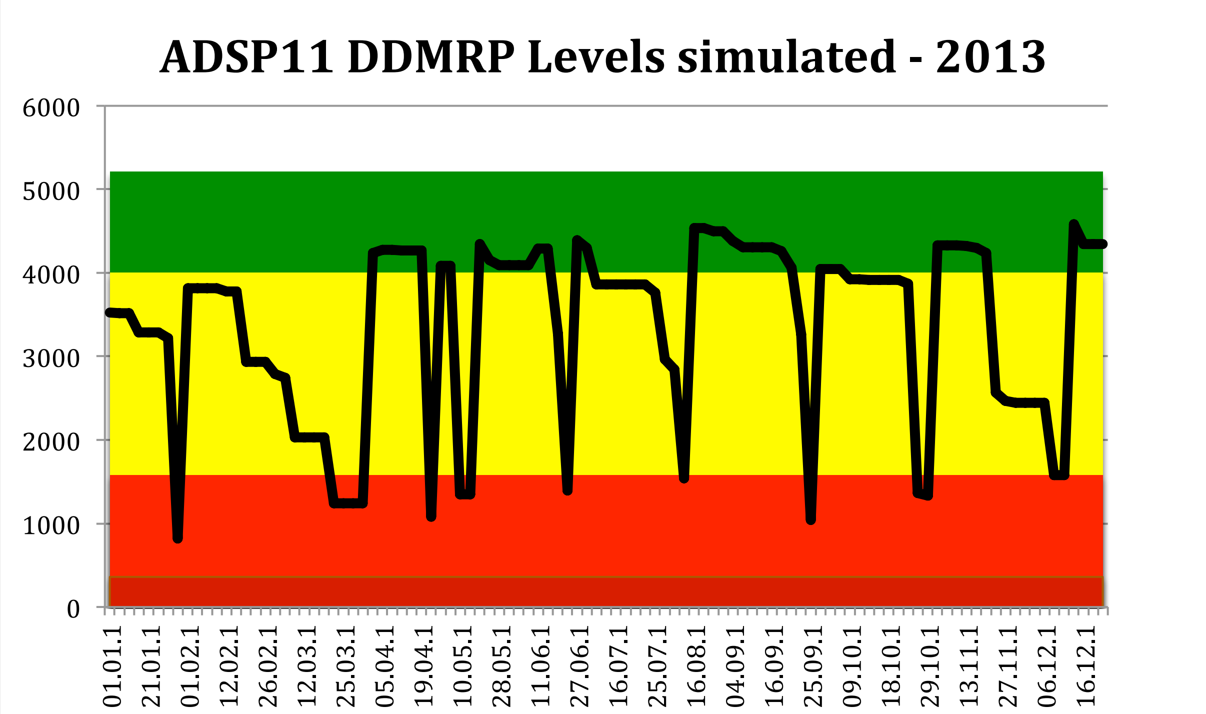


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	216	51	14	0	890
Simulation	216	6	35	0	740

ADSP11 1L

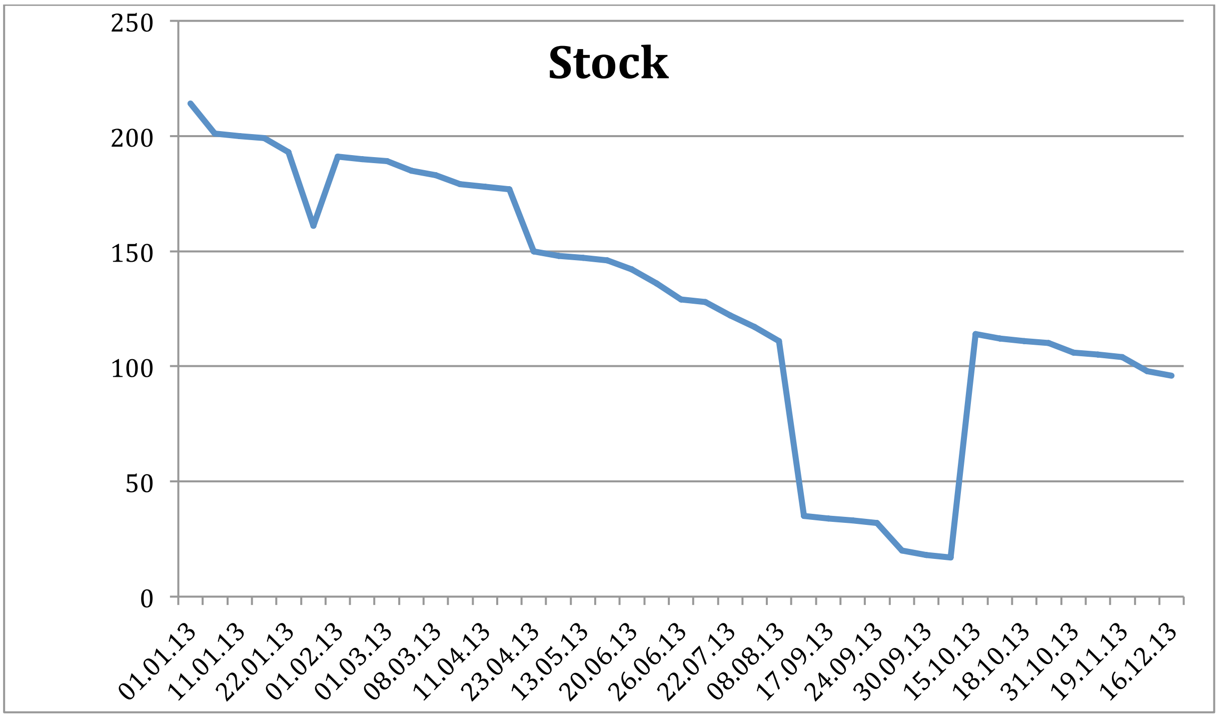

Stock
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
01.01.13
21.01.13
01.02.13
12.02.13
26.02.13
12.03.13
25.03.13
05.04.13
19.04.13
10.05.13
28.05.13
11.06.13
27.06.13
16.07.13
25.07.13
16.08.13
04.09.13
16.09.13
25.09.13
09.10.13
18.10.13
29.10.13
13.11.13
27.11.13
06.12.13
16.12.13

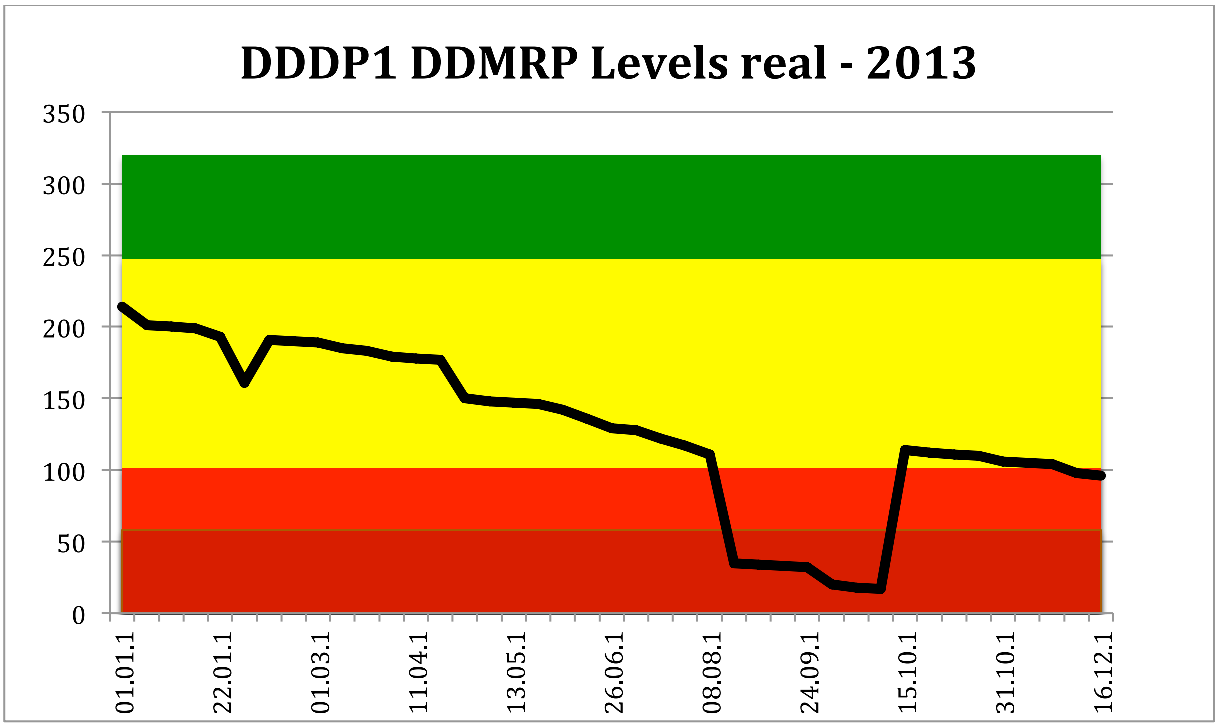

ADSP11 DDMRP Levels real - 2013
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
01.01.1
21.01.1
01.02.1
12.02.1
26.02.1
12.03.1
25.03.1
05.04.1
19.04.1
10.05.1
28.05.1
11.06.1
27.06.1
16.07.1
25.07.1
16.08.1
04.09.1
16.09.1
25.09.1
09.10.1
18.10.1
29.10.1
13.11.1
27.11.1
06.12.1
16.12.1

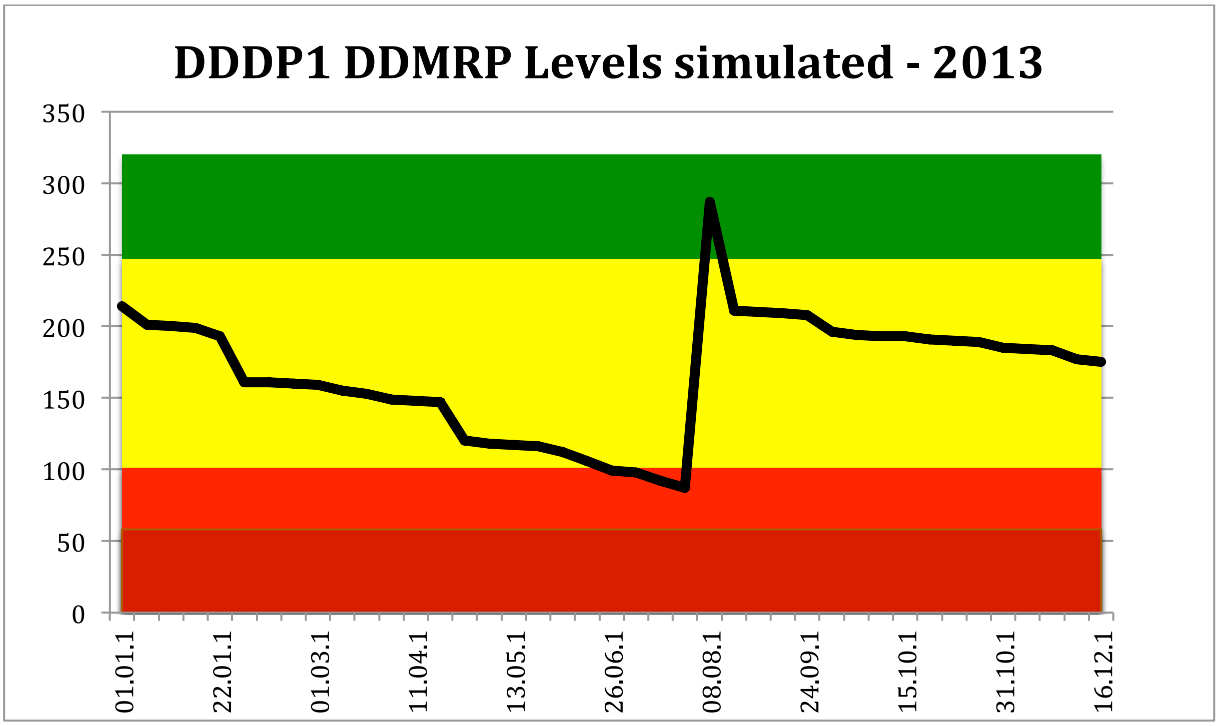


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	105	60	11	0	4261
Simulation	105	42	13	0	3391

DDDP1 1L

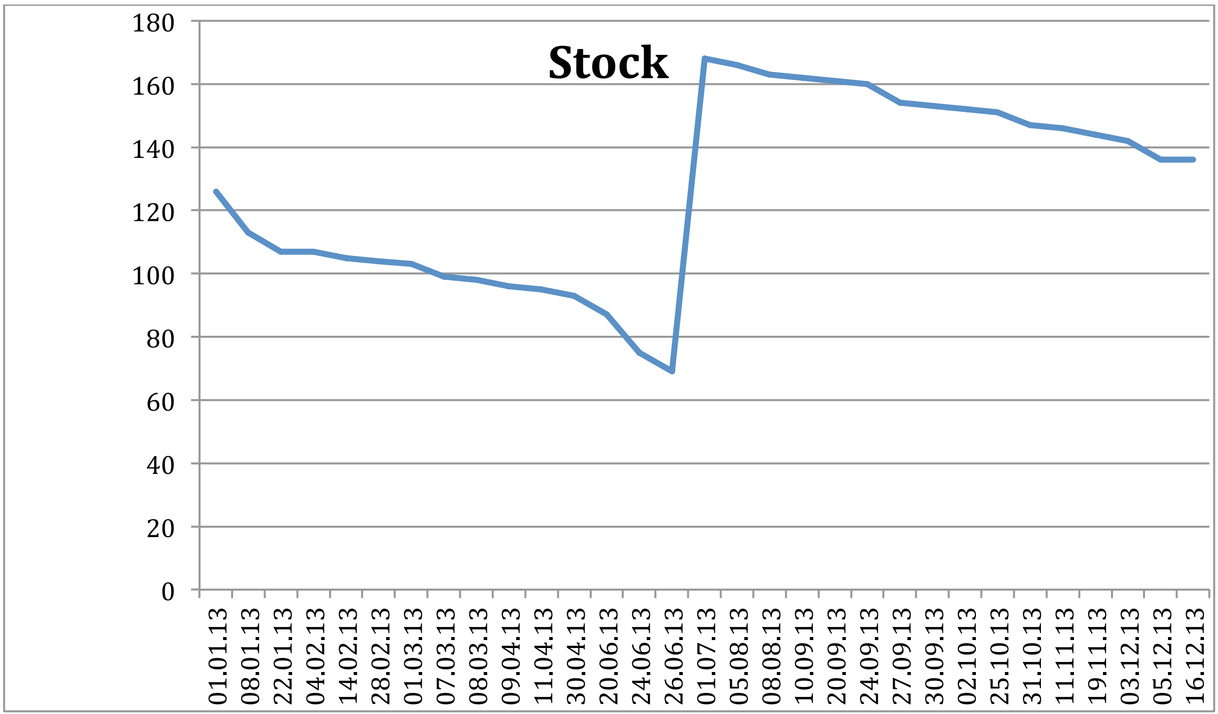

Stock
250
200
150
100
50
0
01.01.13
11.01.13
22.01.13
01.02.13
01.03.13
08.03.13
11.04.13
23.04.13
13.05.13
20.06.13
26.06.13
22.07.13
08.08.13
17.09.13
24.09.13
30.09.13
15.10.13
18.10.13
31.10.13
19.11.13
16.12.13

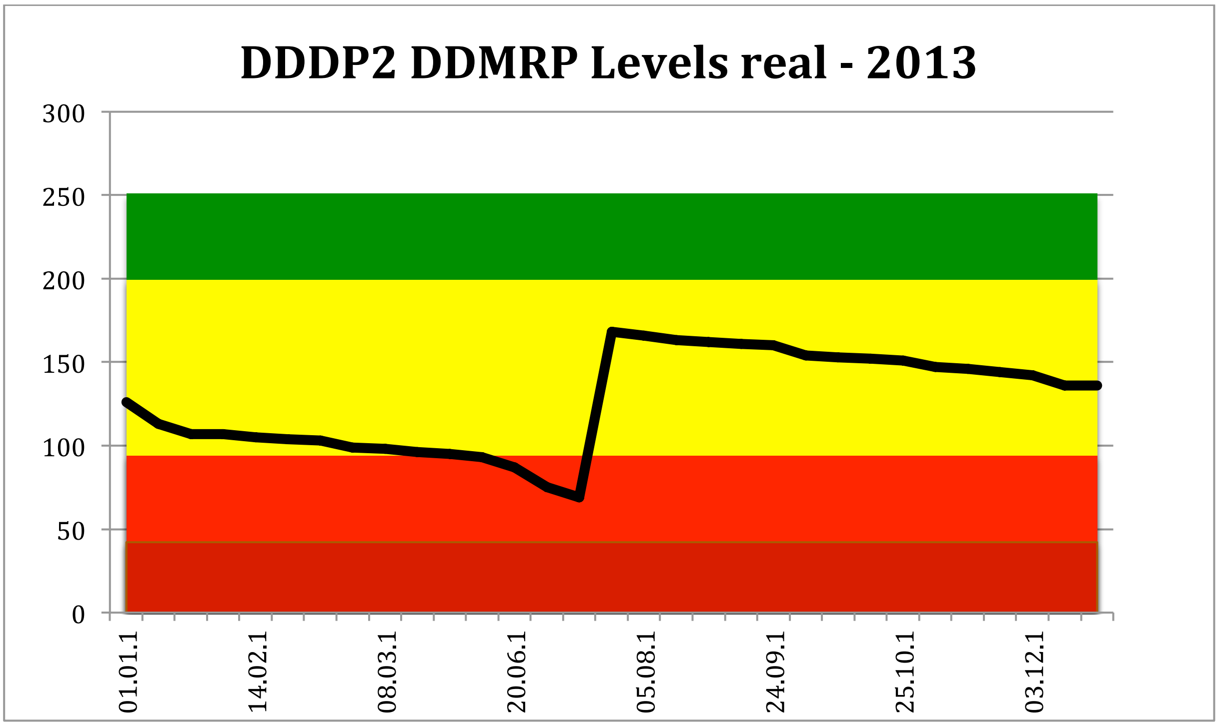

DDDP1 DDMRP Levels real - 2013
350
300
250
200
150
100
50
0
01.01.1
22.01.1
01.03.1
11.04.1
13.05.1
26.06.1
08.08.1
24.09.1
15.10.1
31.10.1
16.12.1

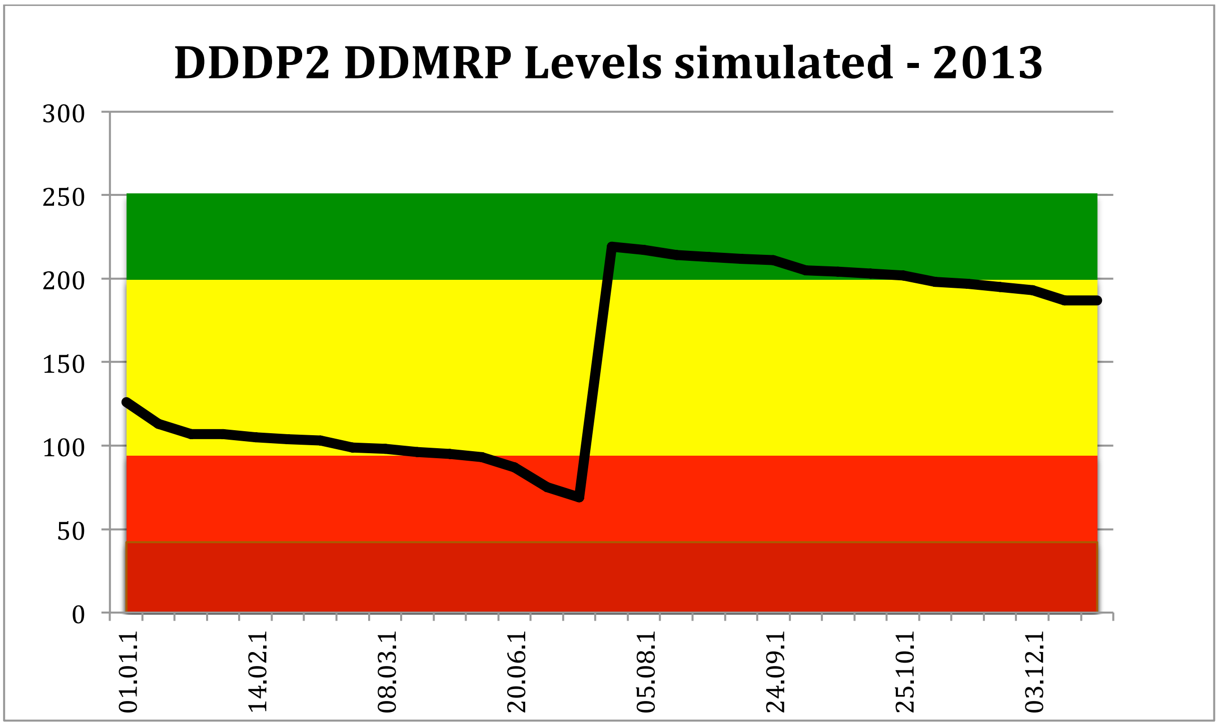


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	43	0	9	7	128
Simulation	43	1	4	0	167

DDDP2 1L

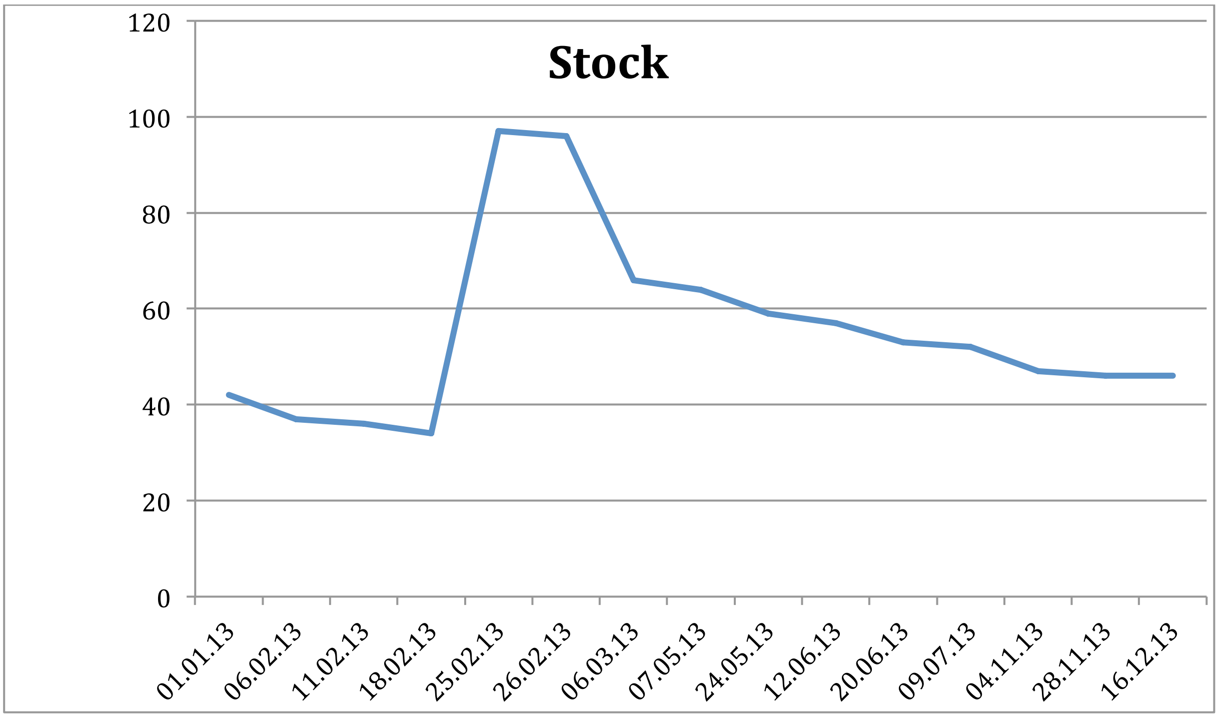

Stock
180
160
140
120
100
80
60
40
20
0
01.01.13
08.01.13
22.01.13
04.02.13
14.02.13
28.02.13
01.03.13
07.03.13
08.03.13
09.04.13
11.04.13
30.04.13
20.06.13
24.06.13
26.06.13
01.07.13
05.08.13
08.08.13
10.09.13
20.09.13
24.09.13
27.09.13
30.09.13
02.10.13
25.10.13
31.10.13
11.11.13
19.11.13
03.12.13
05.12.13
16.12.13

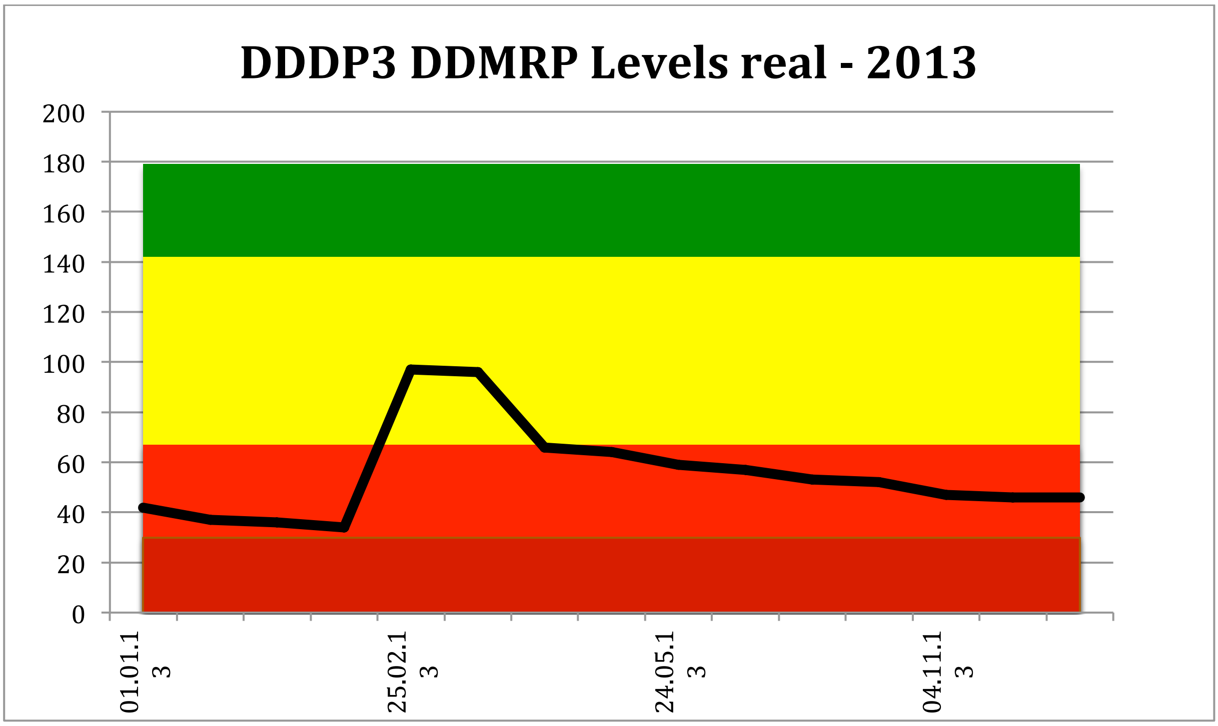

DDDP2 DDMRP Levels real - 2013
300
250
200
150
100
50
0
01.01.1
14.02.1
08.03.1
20.06.1
05.08.1
24.09.1
25.10.1
03.12.1

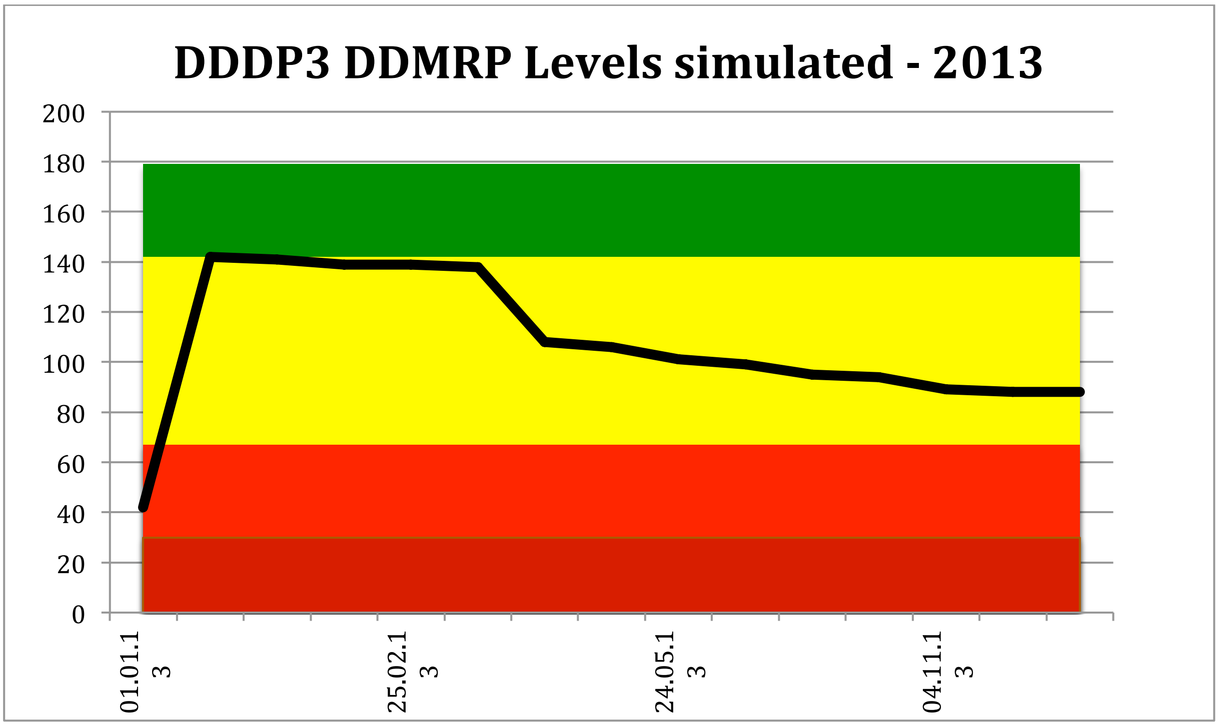


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	33	0	4	0	126
Simulation	33	10	4	0	154

DDDP3 1L

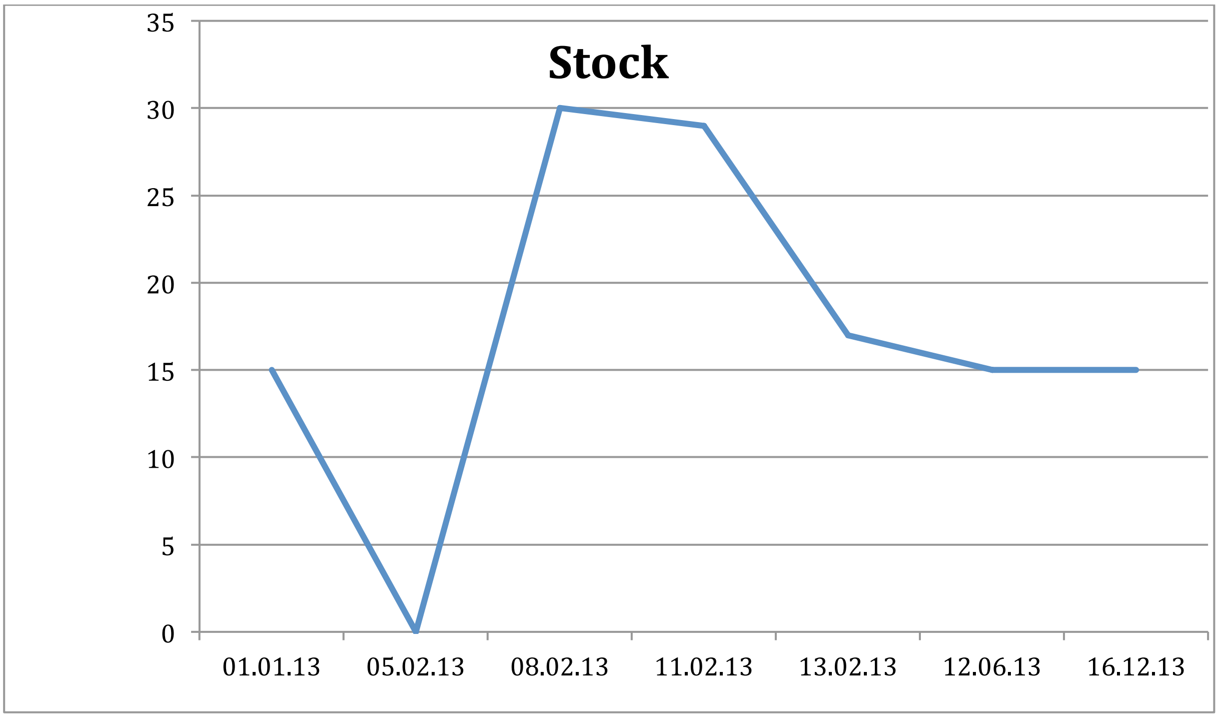

Stock
120
100
80
60
40
20
0
01.01.13
06.02.13
11.02.13
18.02.13
25.02.13
26.02.13
06.03.13
07.05.13
24.05.13
12.06.13
20.06.13
09.07.13
04.11.13
28.11.13
16.12.13

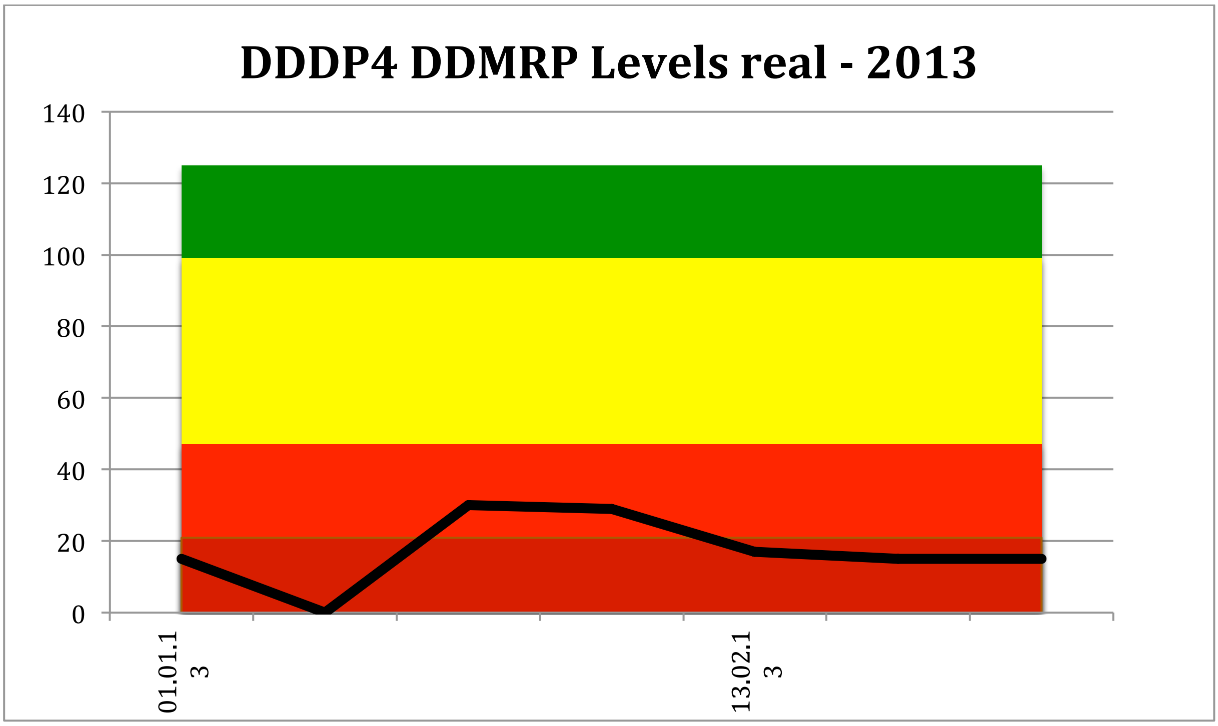

DDDP3 DDMRP Levels real - 2013
200
180
160
140
120
100
80
60
40
20
0
01.01.13
25.02.13
24.05.13
04.11.13

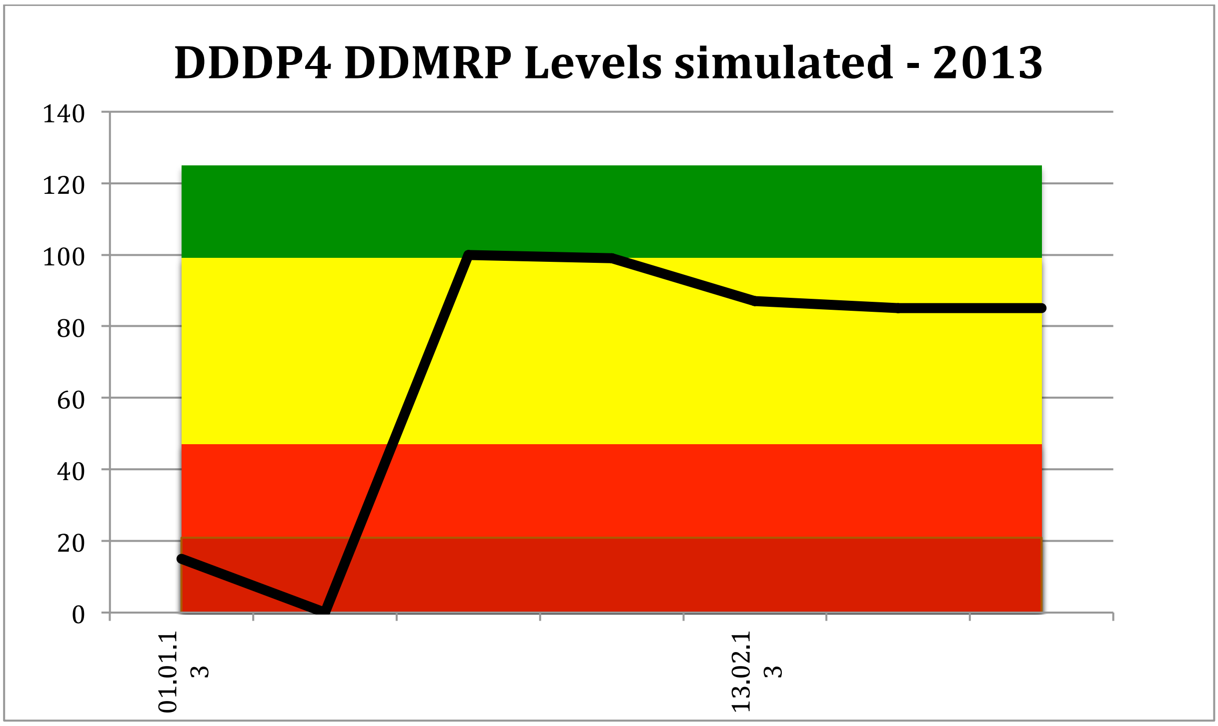


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	17	0	12	0	56
Simulation	17	0	0	0	112

DDDP4 1L

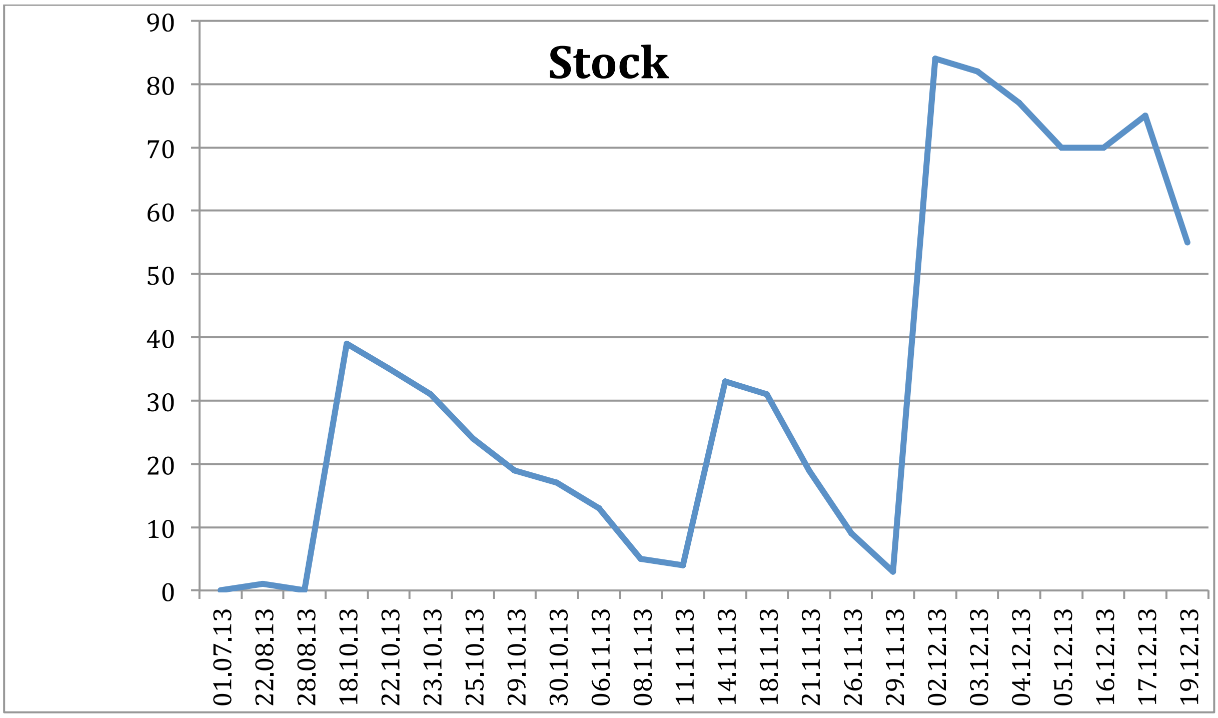

Stock
35
30
25
20
15
10
5
0
01.01.13
05.02.13
08.02.13
11.02.13
13.02.13
12.06.13
16.12.13


DDDP4 DDMRP Levels real - 2013
140
120
100
80
60
40
20
0
01.01.13
13.02.13



Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	9	0	6	4	18
Simulation	9	1	1	1	76

DDDP5 1L


Stock
90
80
70
60
50
40
30
20
10
0
01.07.13
22.08.13
28.08.13
18.10.13
22.10.13
23.10.13
25.10.13
29.10.13
30.10.13
06.11.13
08.11.13
11.11.13
14.11.13
18.11.13
21.11.13
26.11.13
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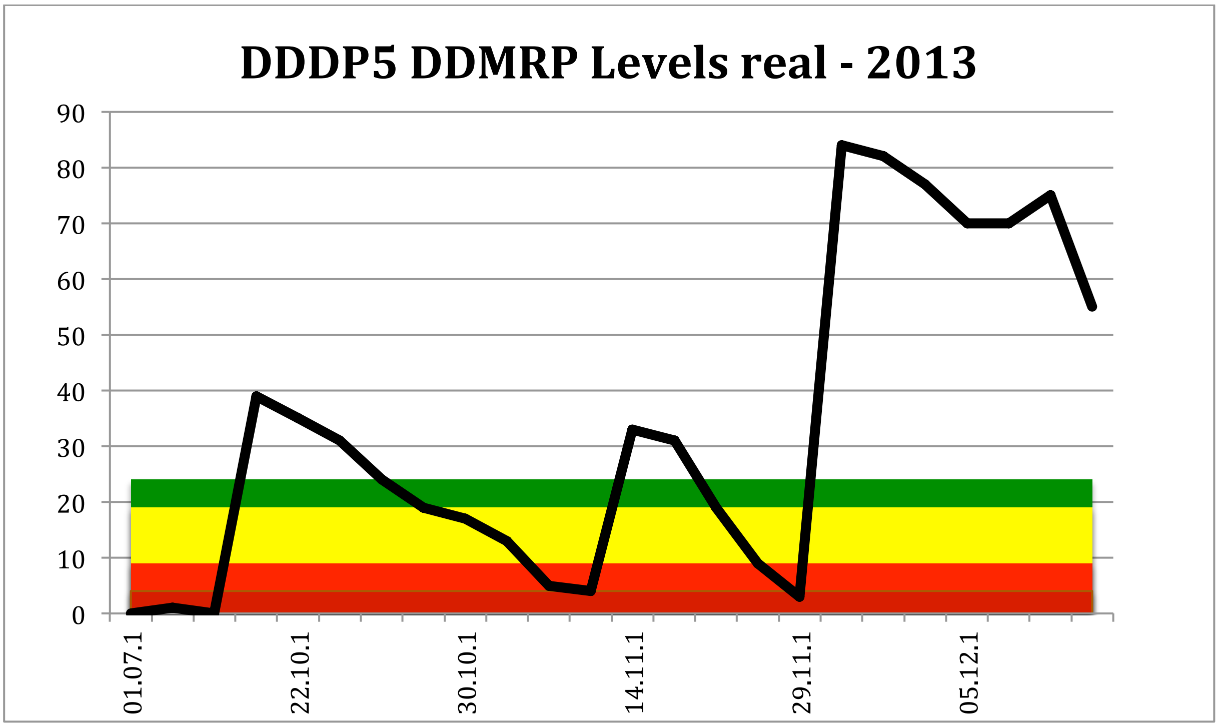
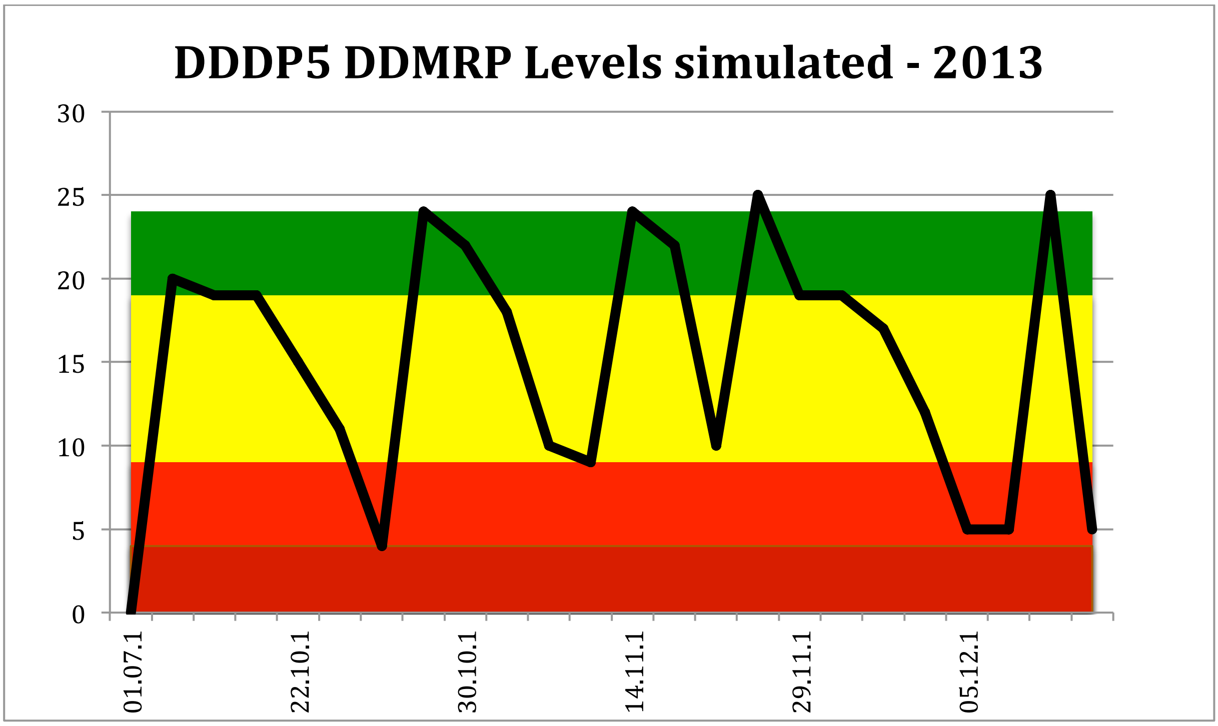
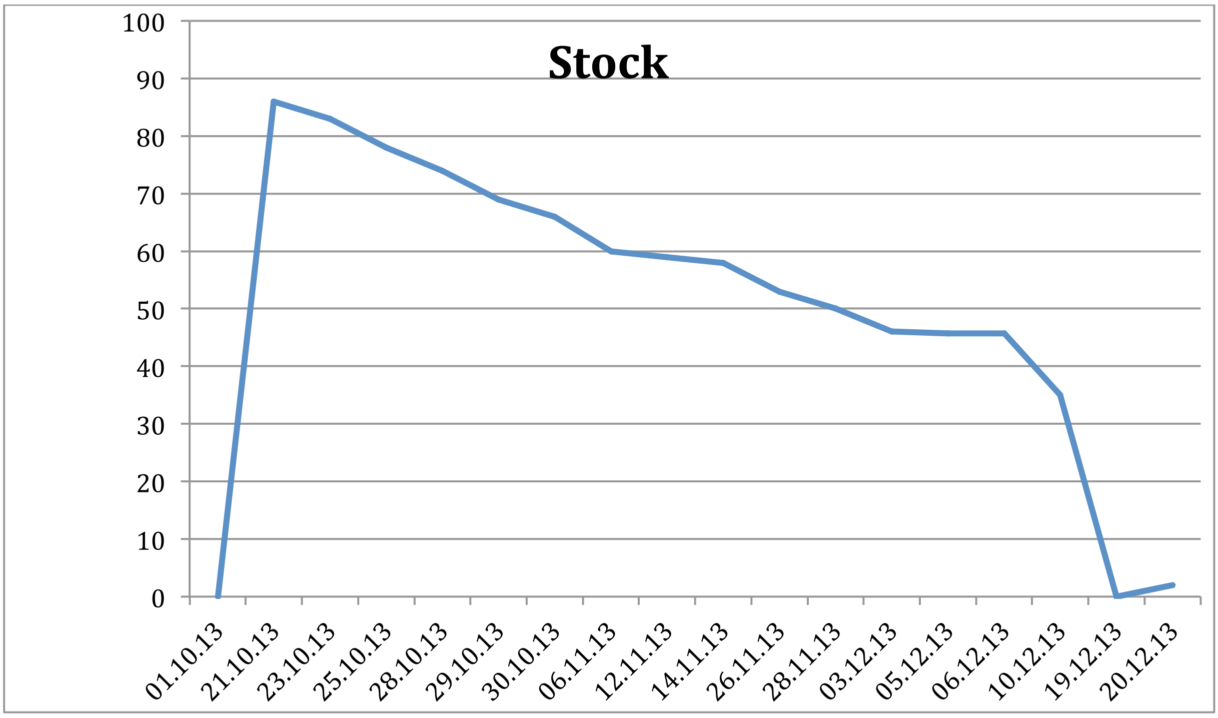
02.12.13
03.12.13
04.12.13
05.12.13
16.12.13
17.12.13
19.12.13

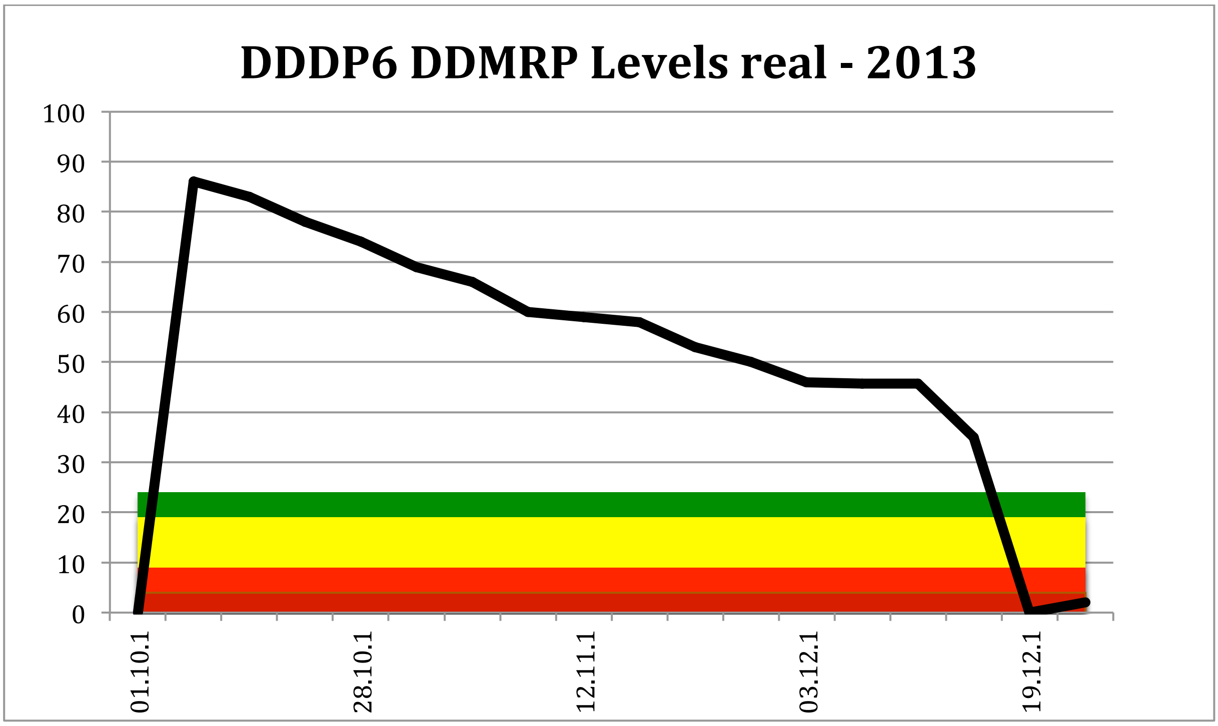

DDDP5 DDMRP Levels real - 2013
90
80
70
60
50
40
30
20
10
0
01.07.1
22.10.1
30.10.1
14.11.1
29.11.1
05.12.1

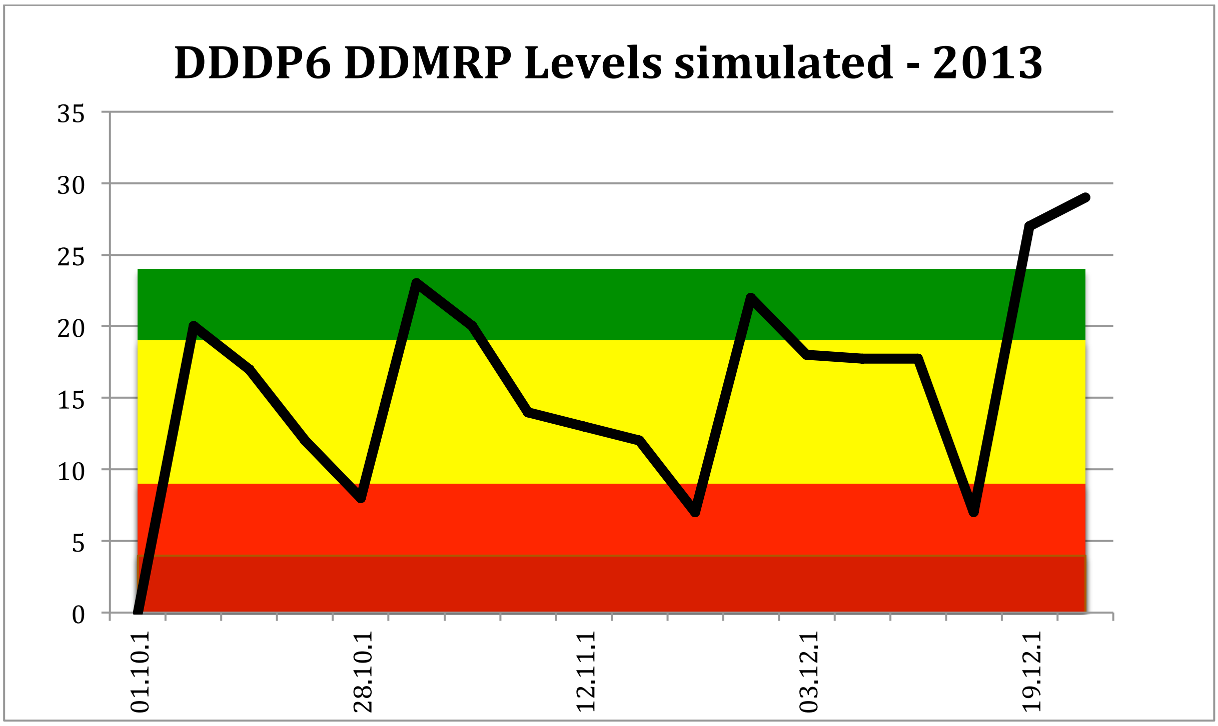


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	26	13	4	3	35
Simulation	26	6	4	0	16

DDDP6 1L

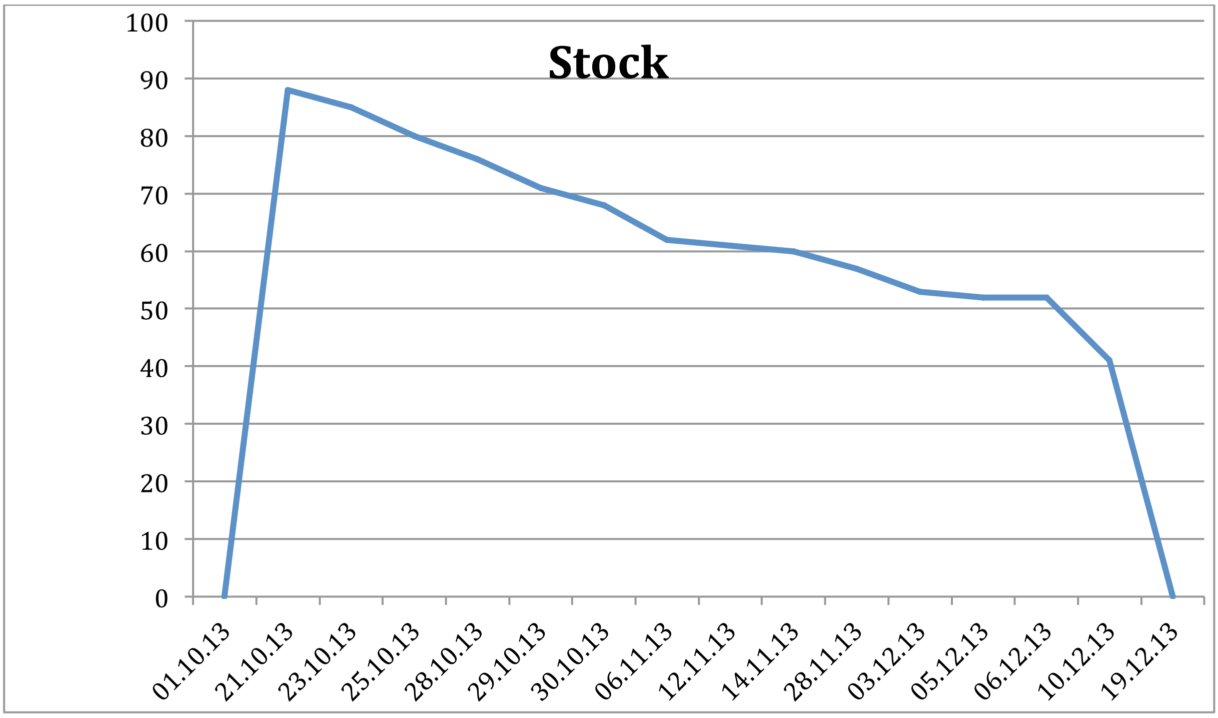

Stock
100
90
80
70
60
50
40
30
20
10
0
01.10.13
21.10.13
23.10.13
25.10.13
28.10.13
29.10.13
30.10.13
06.11.13
12.11.13
14.11.13
26.11.13
28.11.13
03.12.13
05.12.13
06.12.13
10.12.13
19.12.13
20.12.13

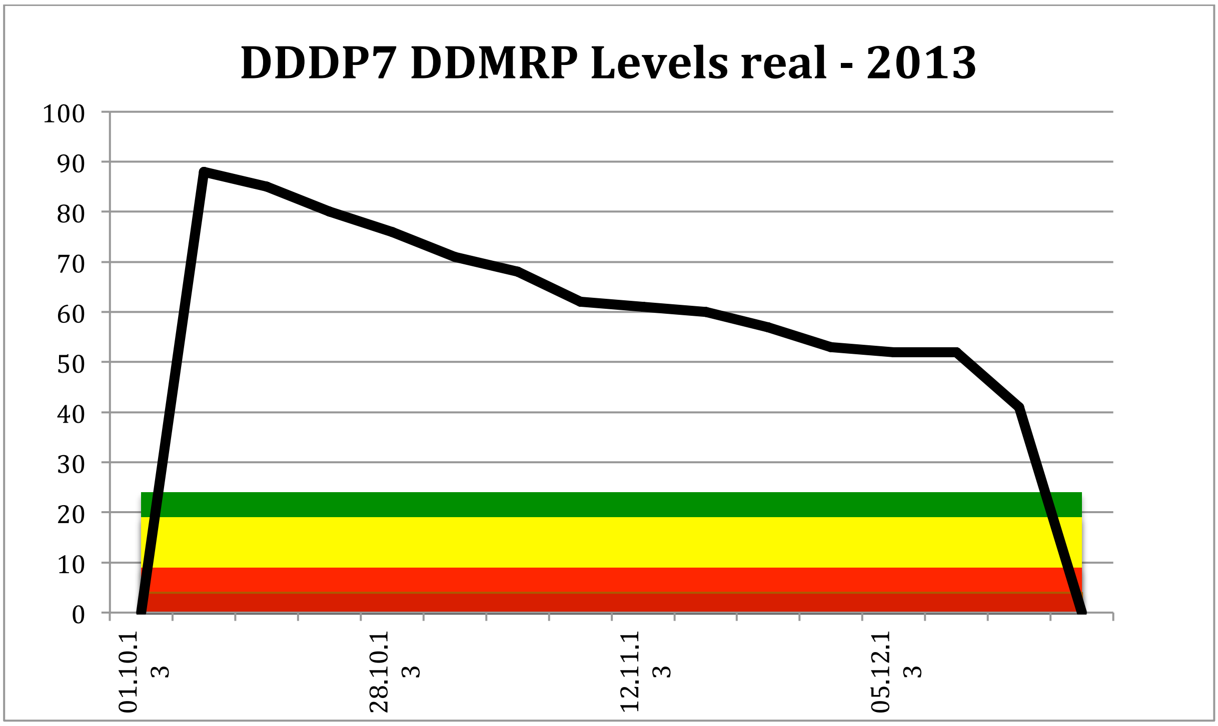

DDDP6 DDMRP Levels real - 2013
100
90
80
70
60
50
40
30
20
10
0
01.10.1
28.10.1
12.11.1
03.12.1
19.12.1

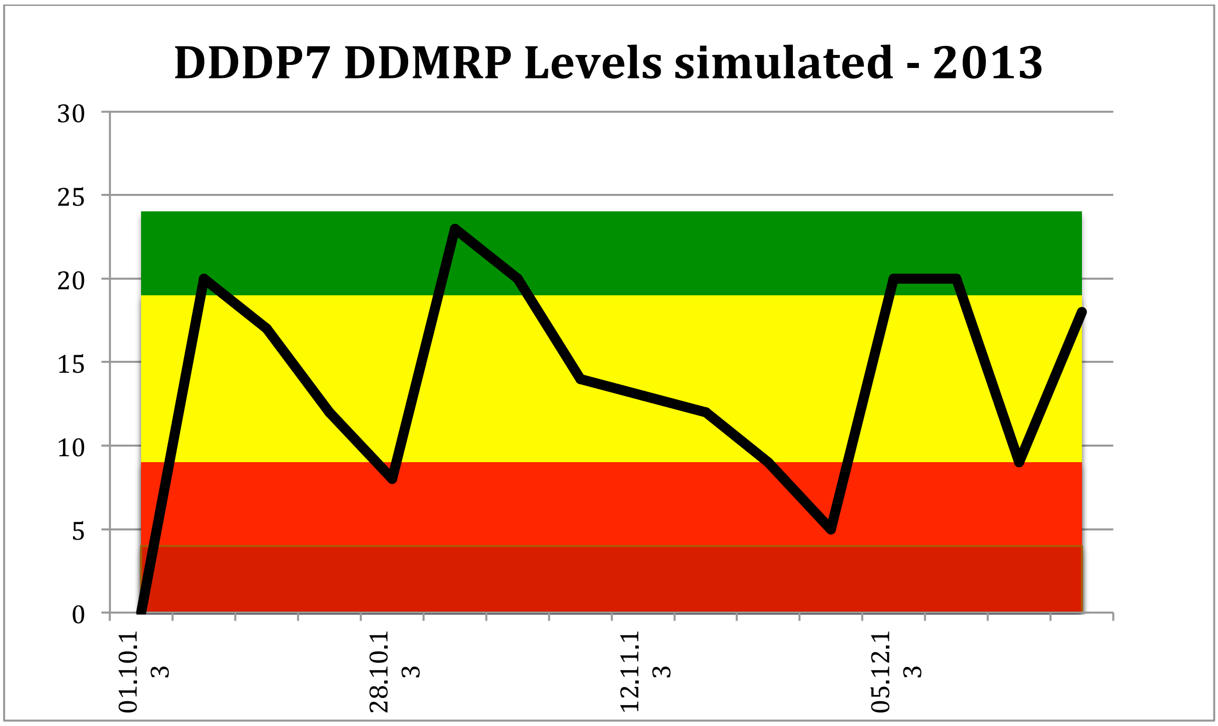


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	20	15	2	2	54
Simulation	20	5	3	0	17

DDDP7 1L

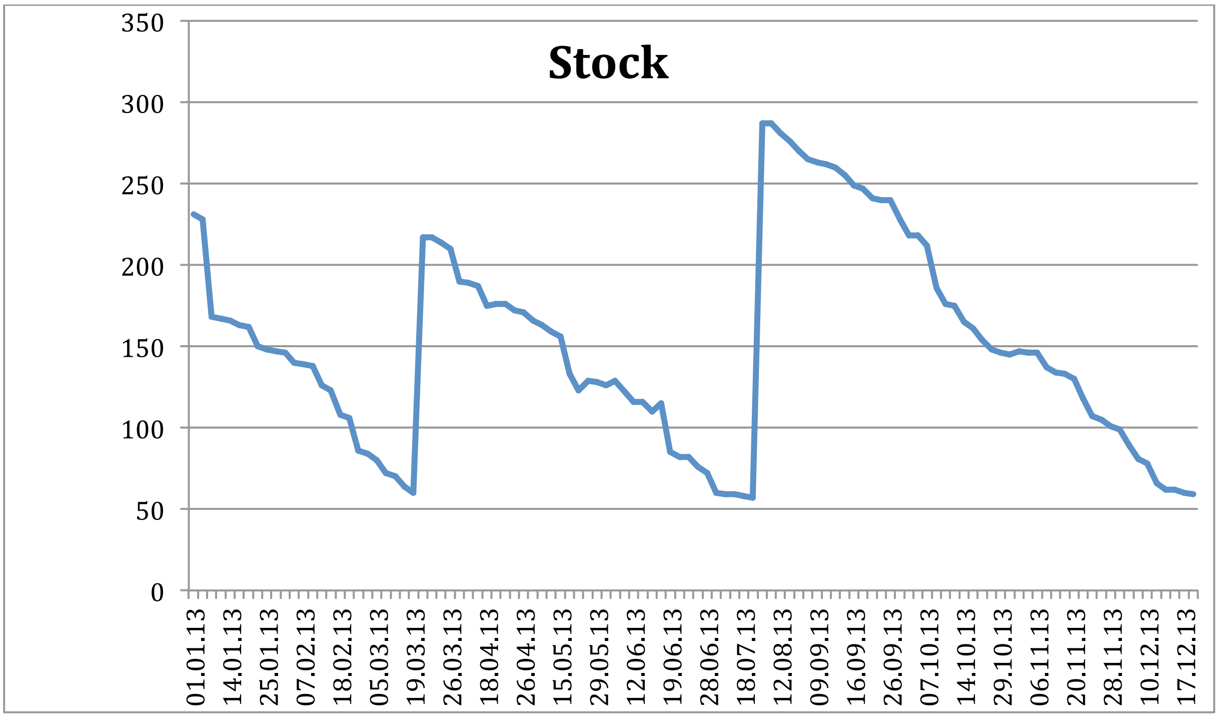

Stock
100
90
80
70
60
50
40
30
20
10
0
01.10.13
21.10.13
23.10.13
25.10.13
28.10.13
29.10.13
30.10.13
06.11.13
12.11.13
14.11.13
28.11.13
03.12.13
05.12.13
06.12.13
10.12.13
19.12.13


DDDP7 DDMRP Levels real - 2013
100
90
80
70
60
50
40
30
20
10
0
01.10.13
28.10.13
12.11.13
05.12.13



Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	18	14	1	1	60
Simulation	18	4	2	0	15

DDDP8 440ML


Stock
350
300
250
200
150
100
50
0
01.01.13
14.01.13
25.01.13
07.02.13
18.02.13
05.03.13
19.03.13
26.03.13
18.04.13
26.04.13
15.05.13
29.05.13
12.06.13
19.06.13
28.06.13
18.07.13
12.08.13
09.09.13
16.09.13
26.09.13
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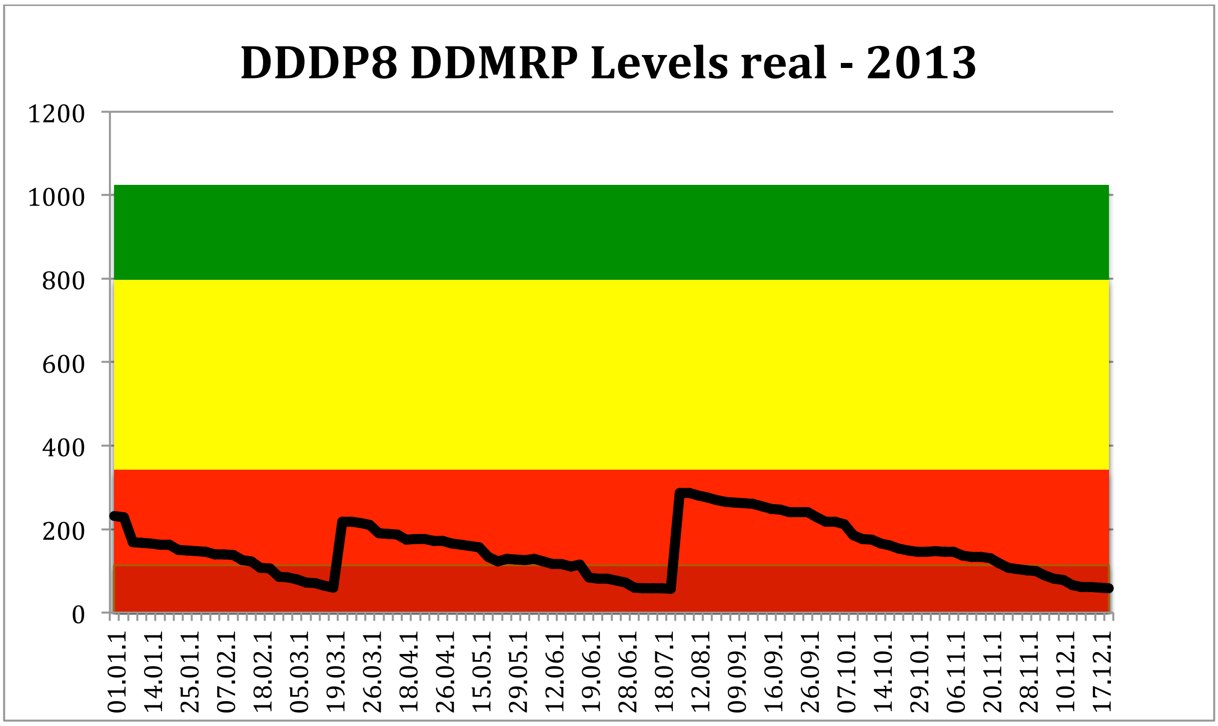
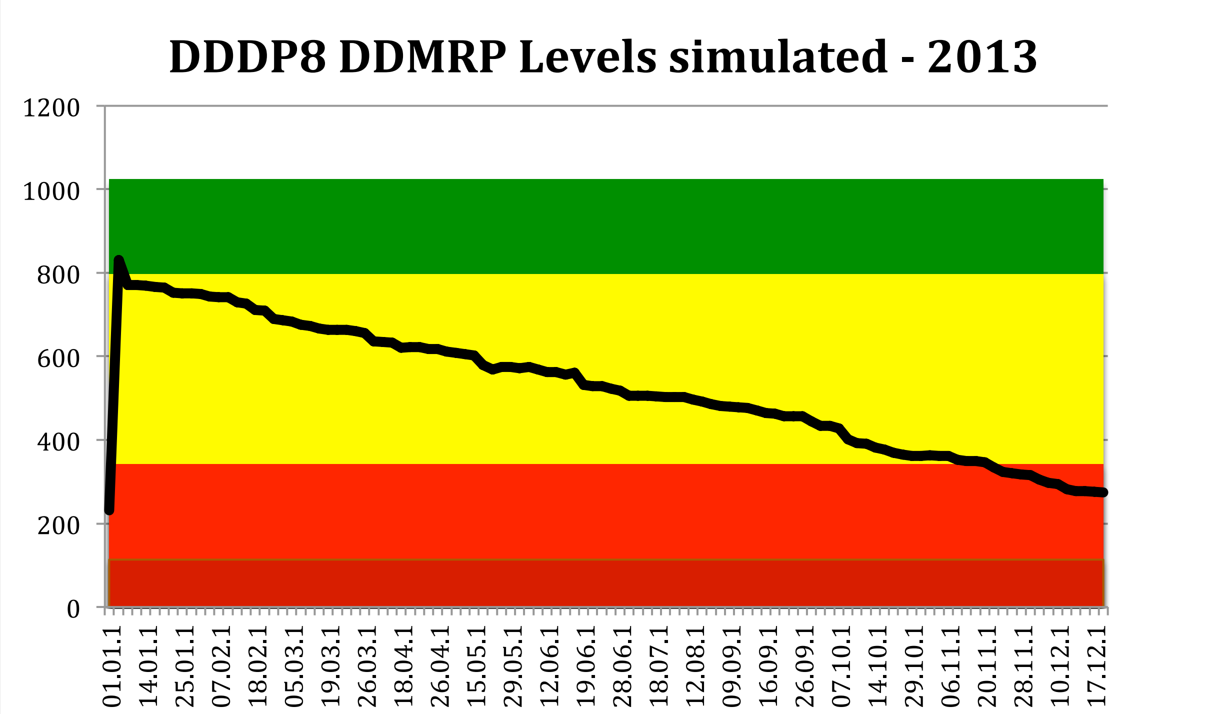
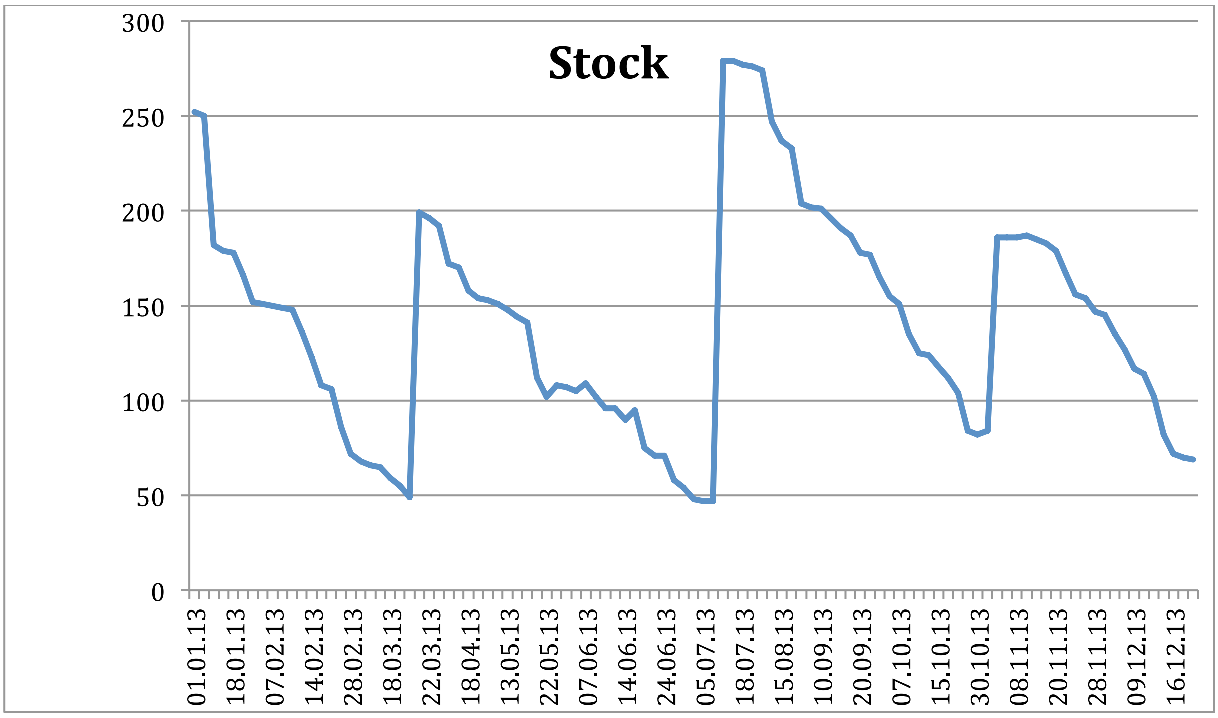
29.10.13
06.11.13
20.11.13
28.11.13
10.12.13
17.12.13


DDDP8 DDMRP Levels real - 2013
1200
1000
800
600
400
200
0
01.01.1
14.01.1
25.01.1
07.02.1
18.02.1
05.03.1
19.03.1
26.03.1
18.04.1
26.04.1
15.05.1
29.05.1
12.06.1
19.06.1
28.06.1
18.07.1
12.08.1
09.09.1
16.09.1
26.09.1
07.10.1
14.10.1
29.10.1
06.11.1
20.11.1
28.11.1
10.12.1
17.12.1



Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	112	0	109	32	150
Simulation	112	0	13	0	529

DDDP9 440ML


Stock
300
250
200
150
100
50
0
01.01.13
18.01.13
07.02.13
14.02.13
28.02.13
18.03.13
22.03.13
18.04.13
13.05.13
22.05.13
07.06.13
14.06.13
24.06.13
05.07.13
18.07.13
15.08.13
10.09.13
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15.10.13
30.10.13
08.11.13
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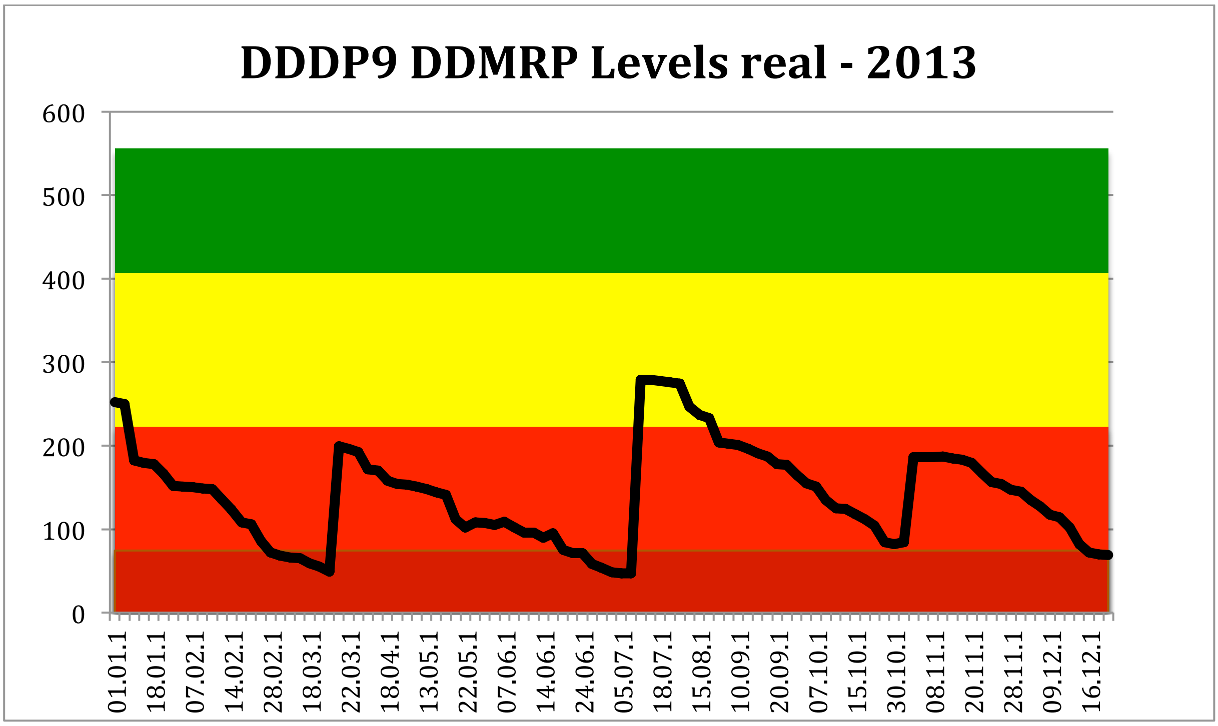
28.11.13
09.12.13
16.12.13


DDDP9 DDMRP Levels real - 2013
600
500
400
300
200
100
0
01.01.1
18.01.1
07.02.1
14.02.1
28.02.1
18.03.1
22.03.1
18.04.1
13.05.1
22.05.1
07.06.1
14.06.1
24.06.1
05.07.1
18.07.1
15.08.1
10.09.1
20.09.1
07.10.1
15.10.1
30.10.1
08.11.1
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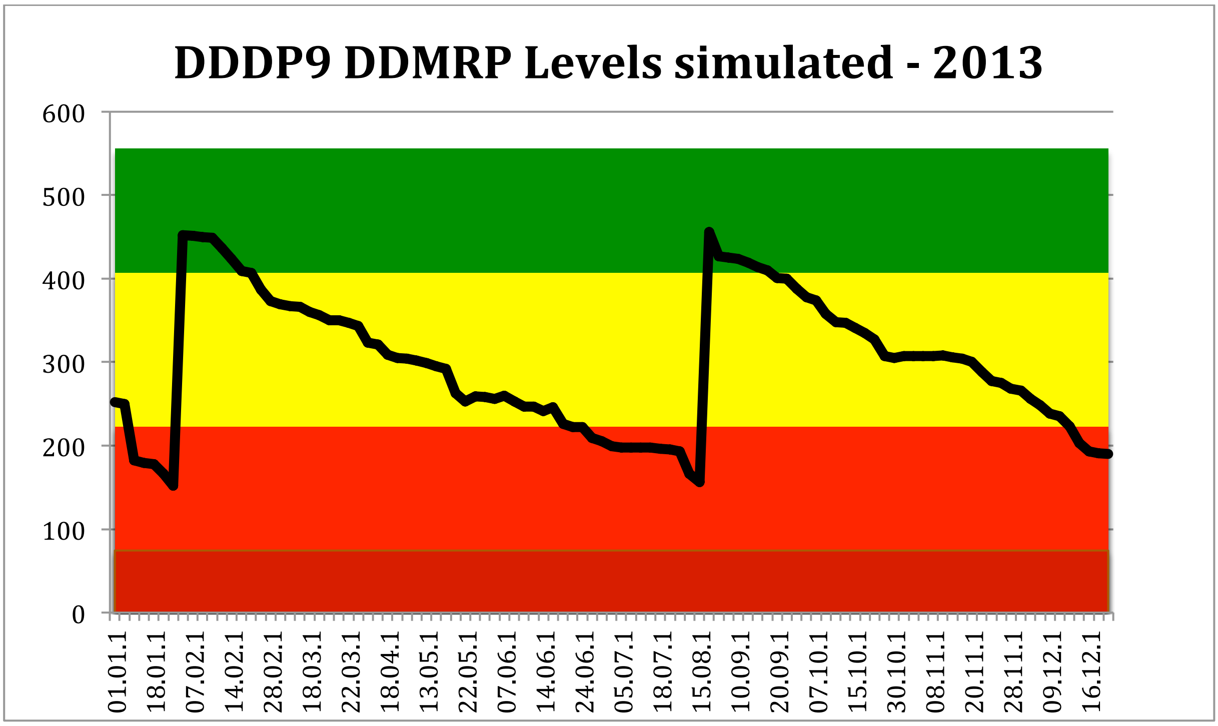
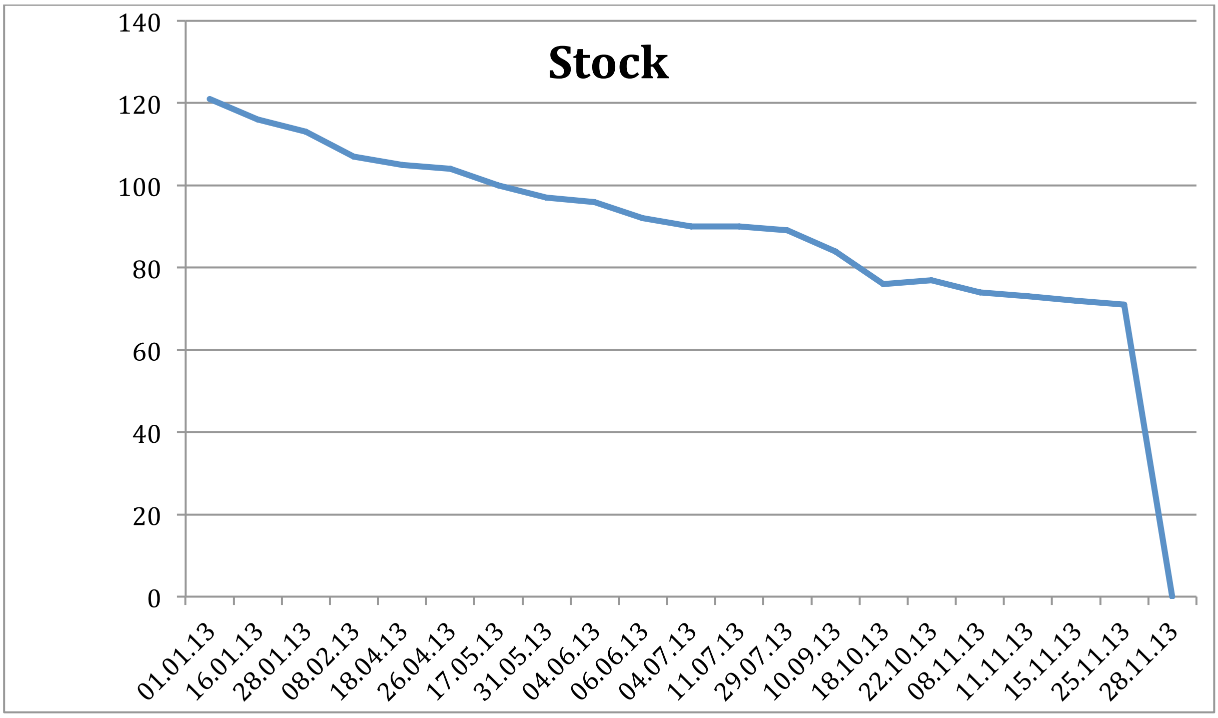
28.11.1
09.12.1
16.12.1



Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	105	0	93	17	140
Simulation	105	14	21	0	299

DDDP10 1L


Stock
140
120
100
80
60
40
20
0
01.01.13
16.01.13
28.01.13
08.02.13
18.04.13
26.04.13
17.05.13
31.05.13
04.06.13
06.06.13
04.07.13
11.07.13
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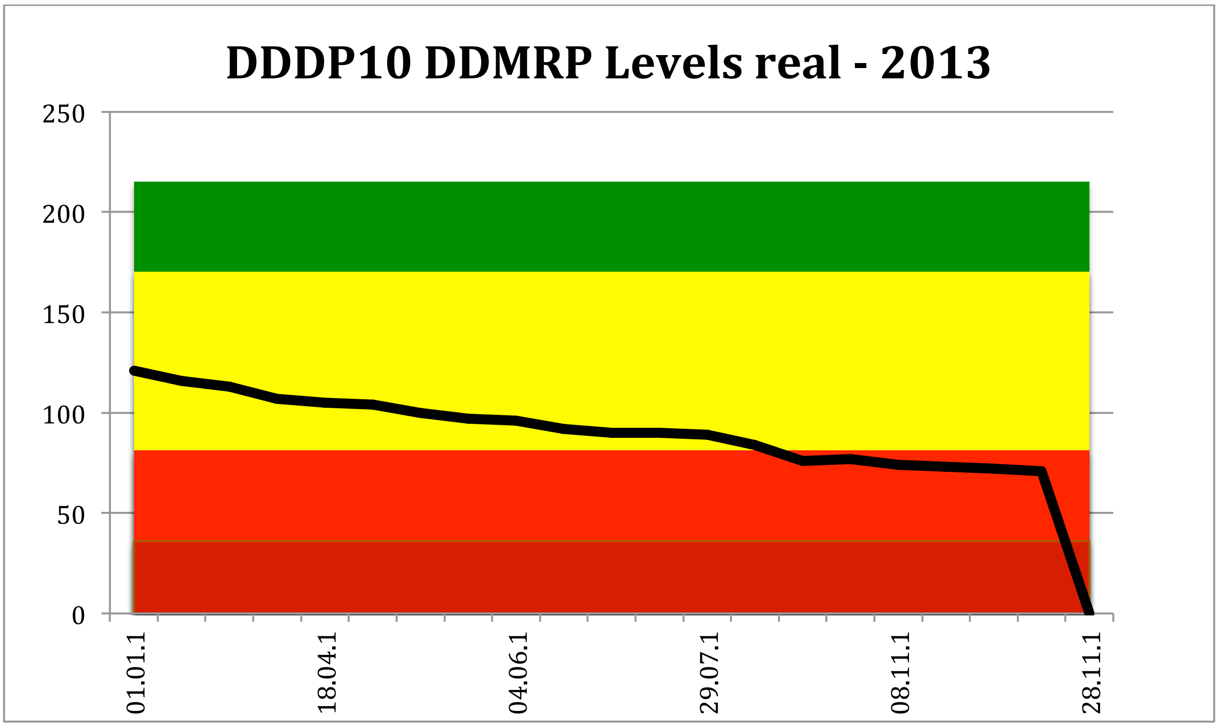
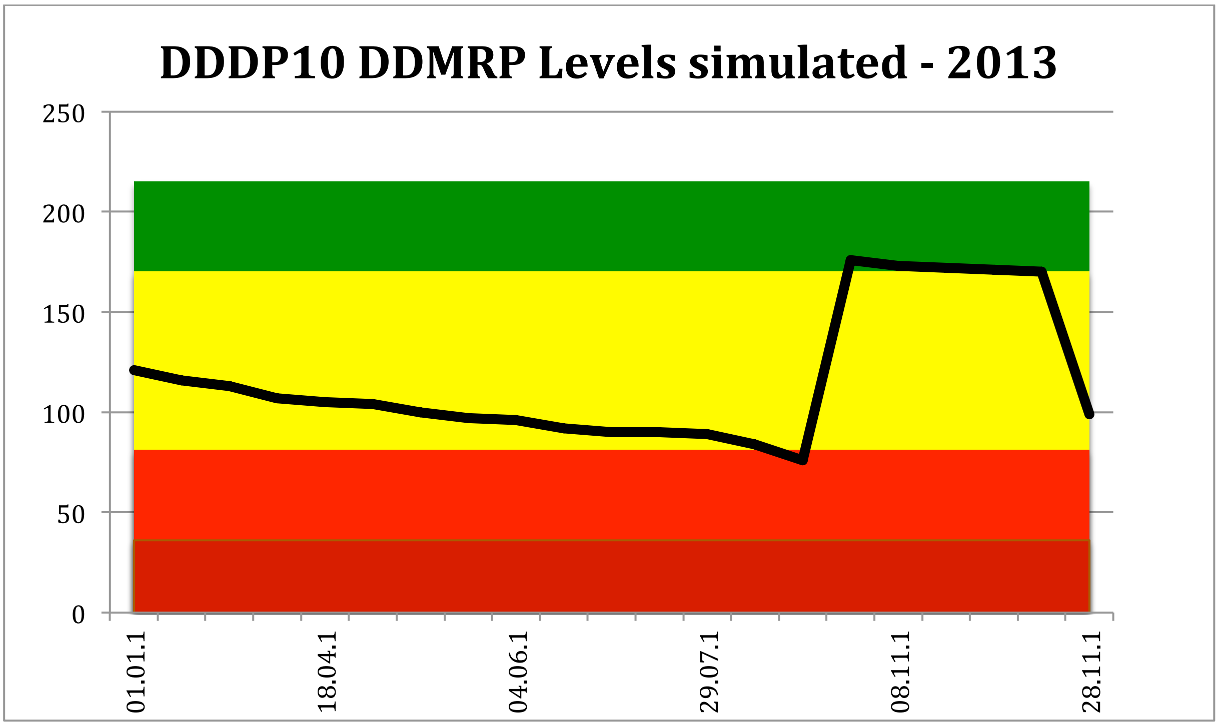
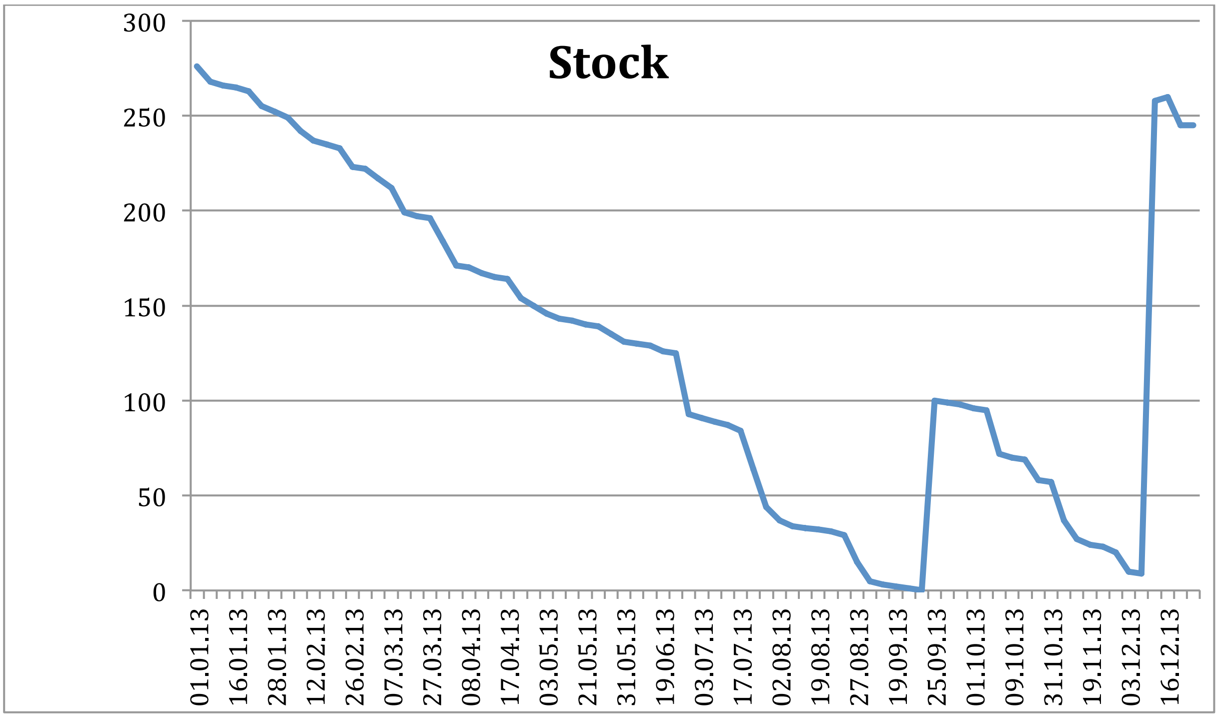
11.11.13
15.11.13
25.11.13
28.11.13


DDDP10 DDMRP Levels real - 2013
250
200
150
100
50
0
01.01.1
18.04.1
04.06.1
29.07.1
08.11.1
28.11.1



Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	23	0	7	1	86
Simulation	23	4	1	0	116

ADSP12 5KG


Stock
300
250
200
150
100
50
0
01.01.13
16.01.13
28.01.13
12.02.13
26.02.13
07.03.13
27.03.13
08.04.13
17.04.13
03.05.13
21.05.13
31.05.13
19.06.13
03.07.13
17.07.13
02.08.13
19.08.13
27.08.13
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25.09.13
01.10.13
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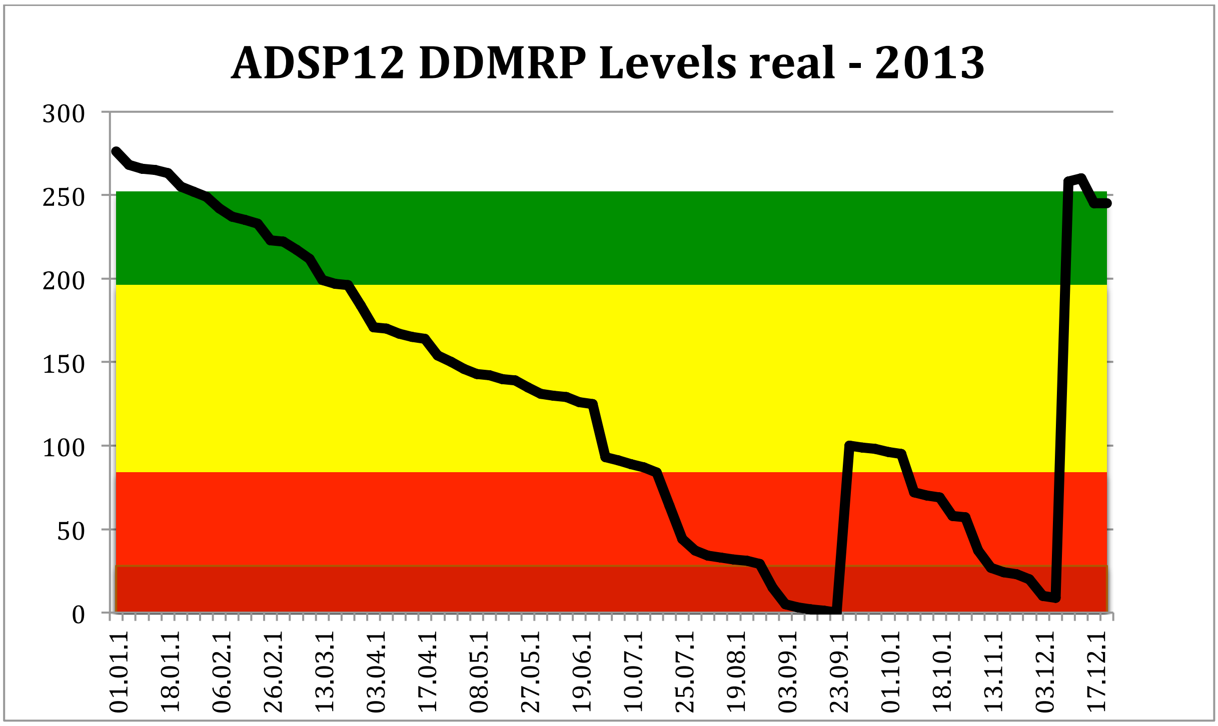
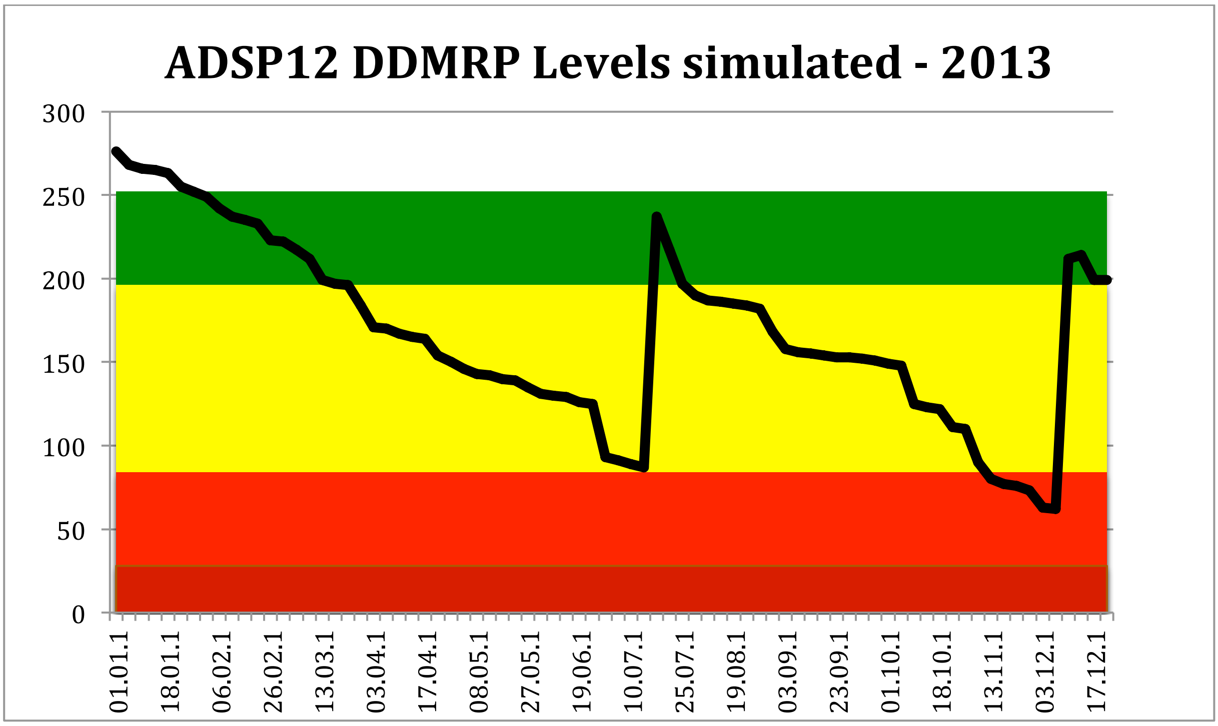
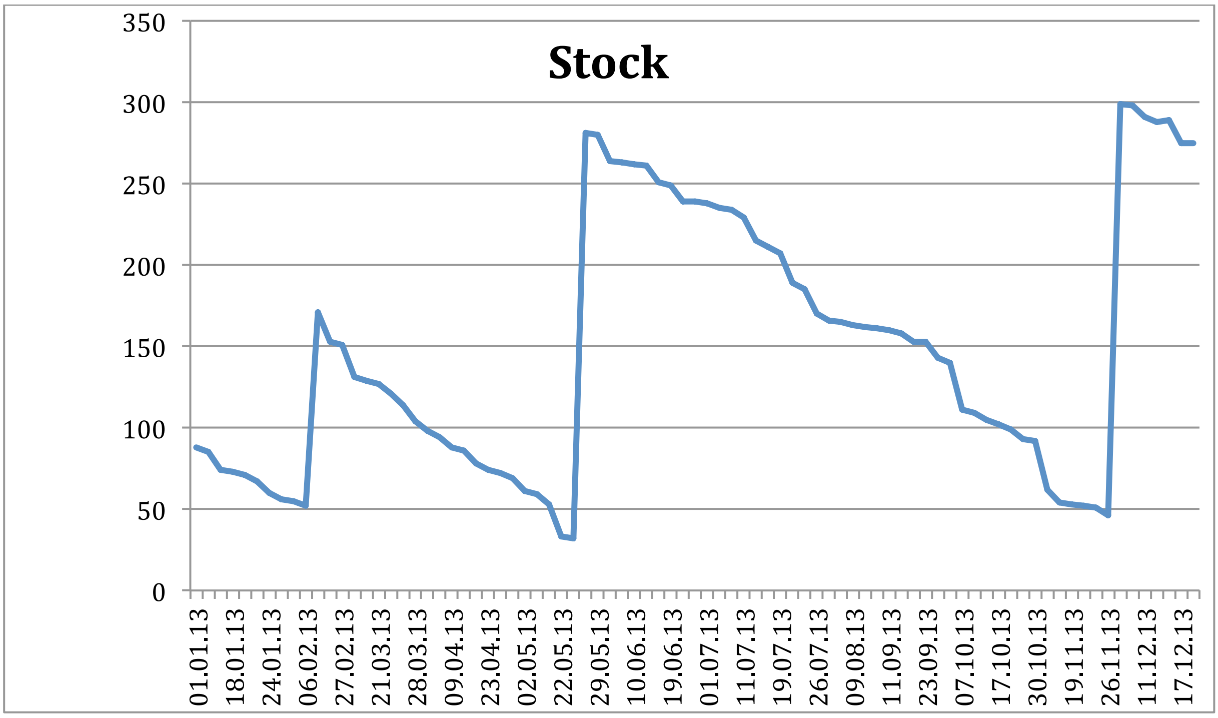
31.10.13
19.11.13
03.12.13
16.12.13


ADSP12 DDMRP Levels real - 2013
300
250
200
150
100
50
0
01.01.1
18.01.1
06.02.1
26.02.1
13.03.1
03.04.1
17.04.1
08.05.1
27.05.1
19.06.1
10.07.1
25.07.1
19.08.1
03.09.1
23.09.1
01.10.1
18.10.1
13.11.1
03.12.1
17.12.1



Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	80	21	26	12	127
Simulation	80	23	6	0	166

ADSP13 5KG


Stock
350
300
250
200
150
100
50
0
01.01.13
18.01.13
24.01.13
06.02.13
27.02.13
21.03.13
28.03.13
09.04.13
23.04.13
02.05.13
22.05.13
29.05.13
10.06.13
19.06.13
01.07.13
11.07.13
19.07.13
26.07.13
09.08.13
11.09.13
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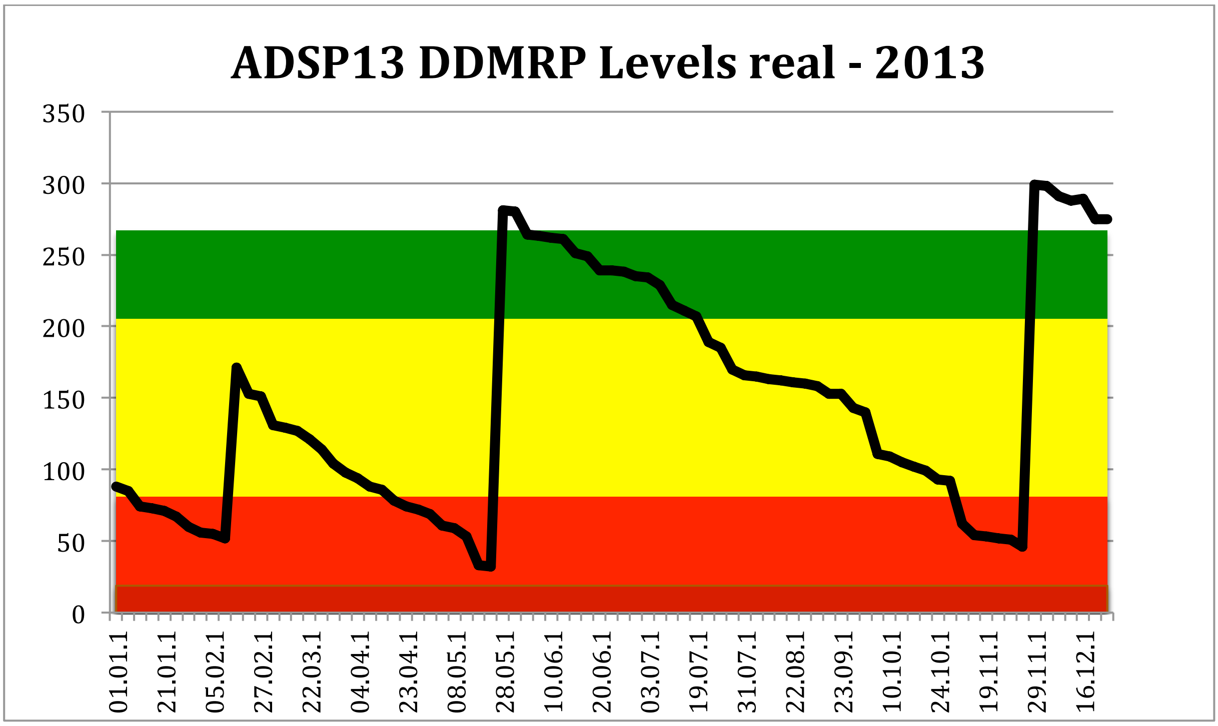
26.11.13
11.12.13
17.12.13


ADSP13 DDMRP Levels real - 2013
350
300
250
200
150
100
50
0
01.01.1
21.01.1
05.02.1
27.02.1
22.03.1
04.04.1
23.04.1
08.05.1
28.05.1
10.06.1
20.06.1
03.07.1
19.07.1
31.07.1
22.08.1
23.09.1
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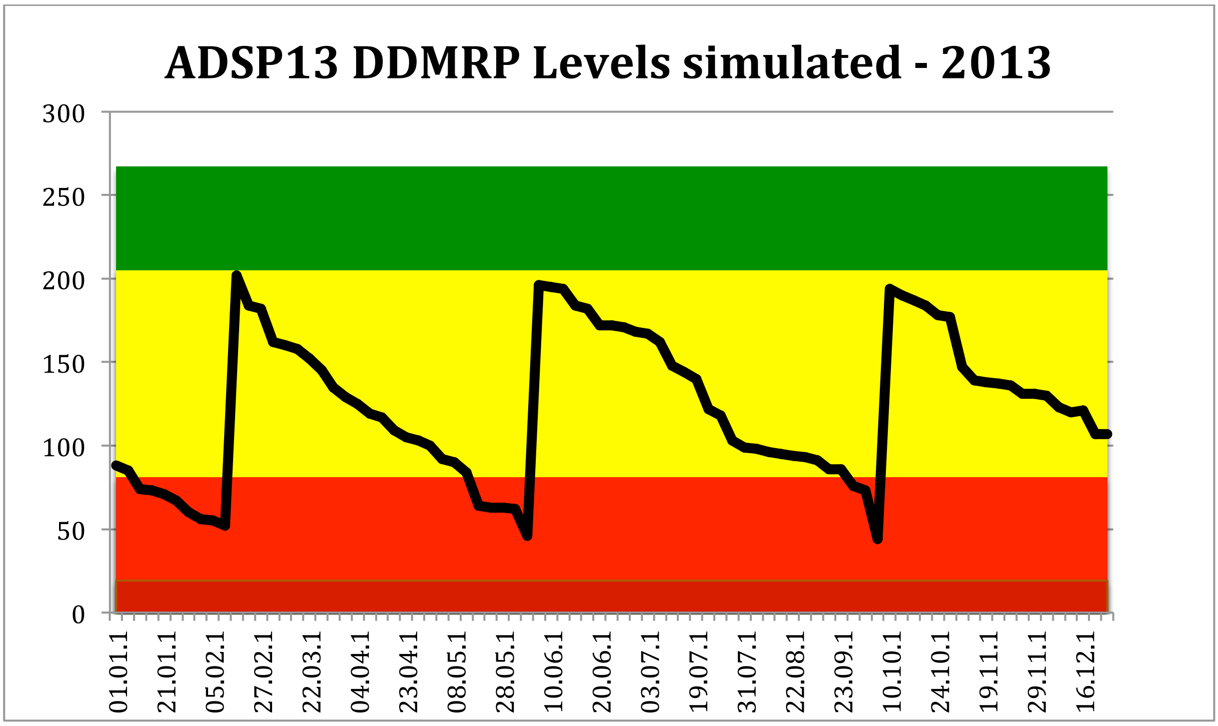
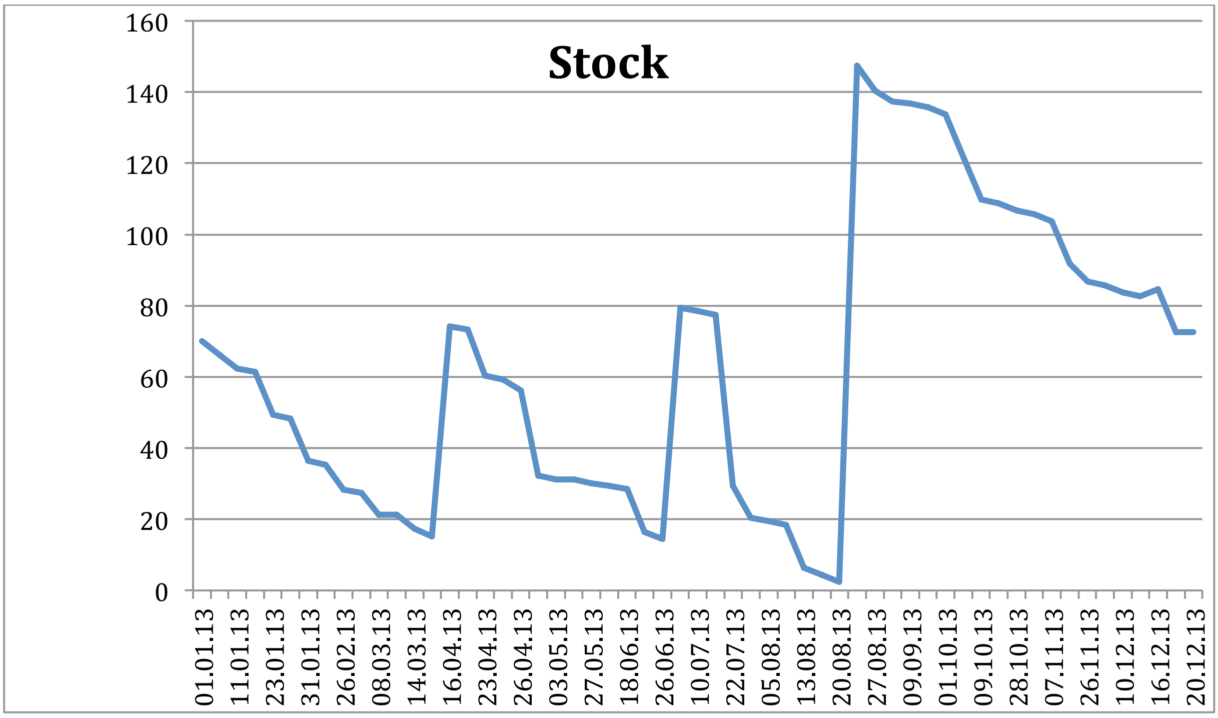
19.11.1
29.11.1
16.12.1



Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	85	24	23	0	148
Simulation	85	0	16	0	123

ADPP1 1L


Stock
0
20
40
60
80
100
120
140
160
01.01.13
11.01.13
23.01.13
31.01.13
26.02.13
08.03.13
14.03.13
16.04.13
23.04.13
26.04.13
03.05.13
27.05.13
18.06.13
26.06.13
10.07.13
22.07.13
05.08.13
13.08.13
20.08.13
27.08.13
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28.10.13
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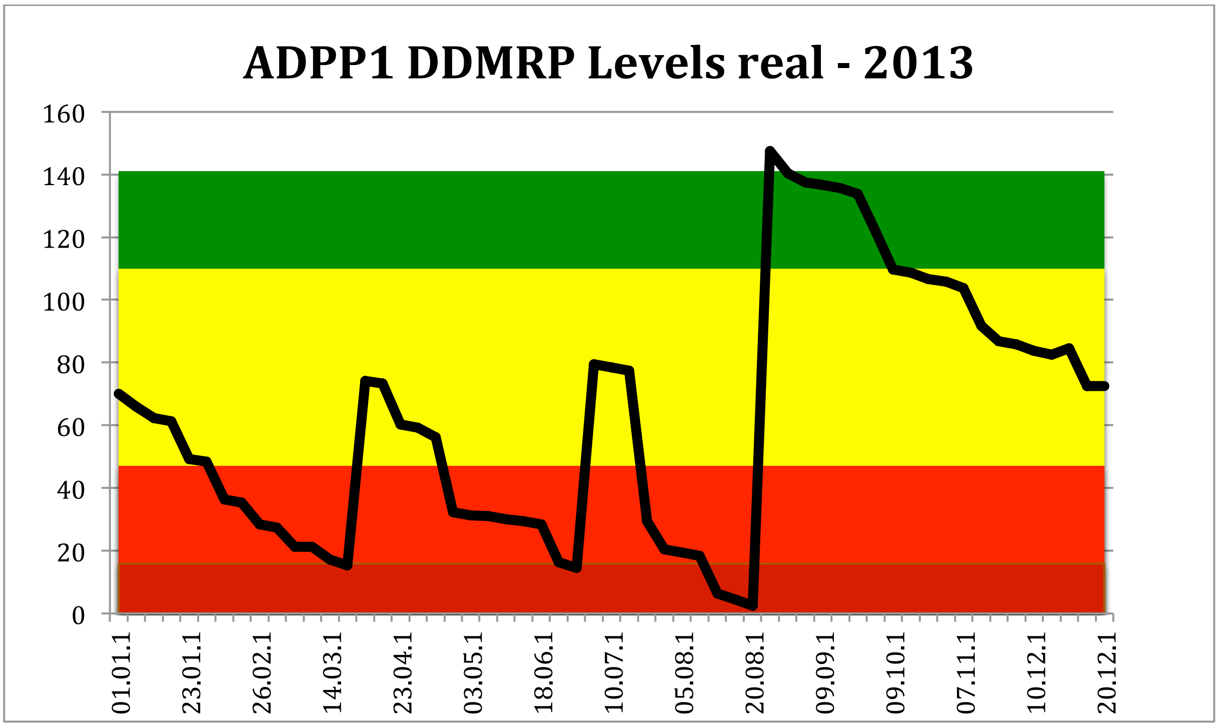
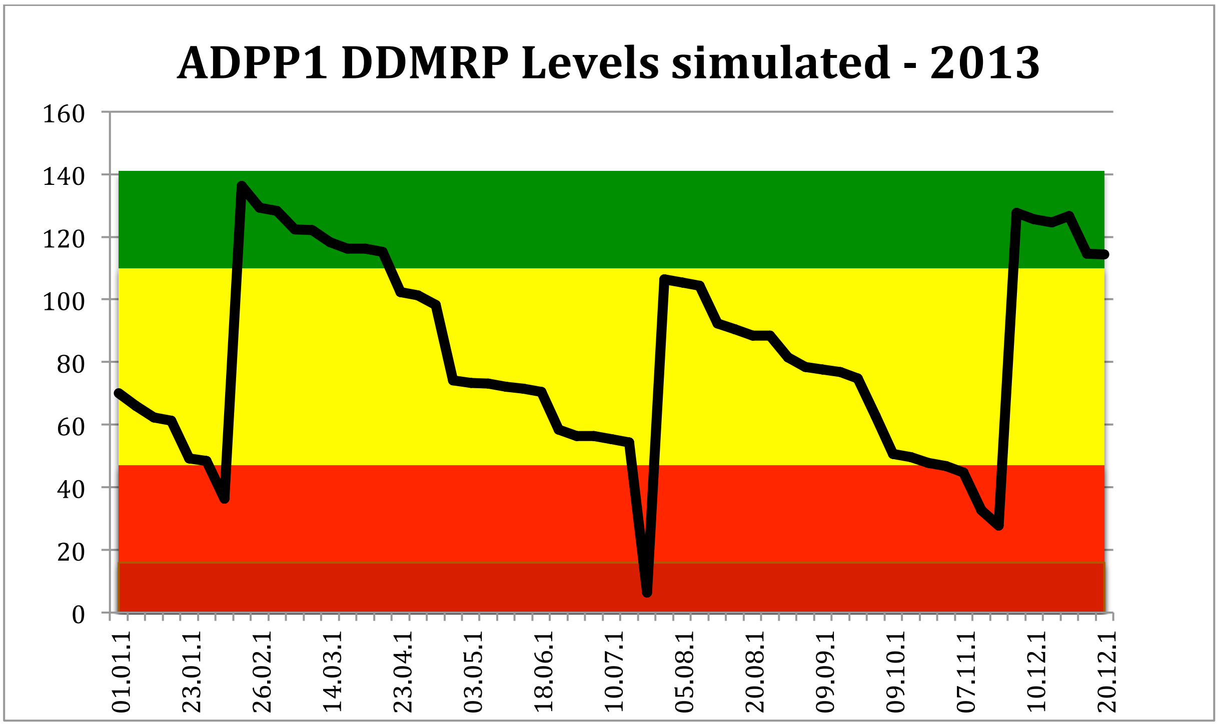
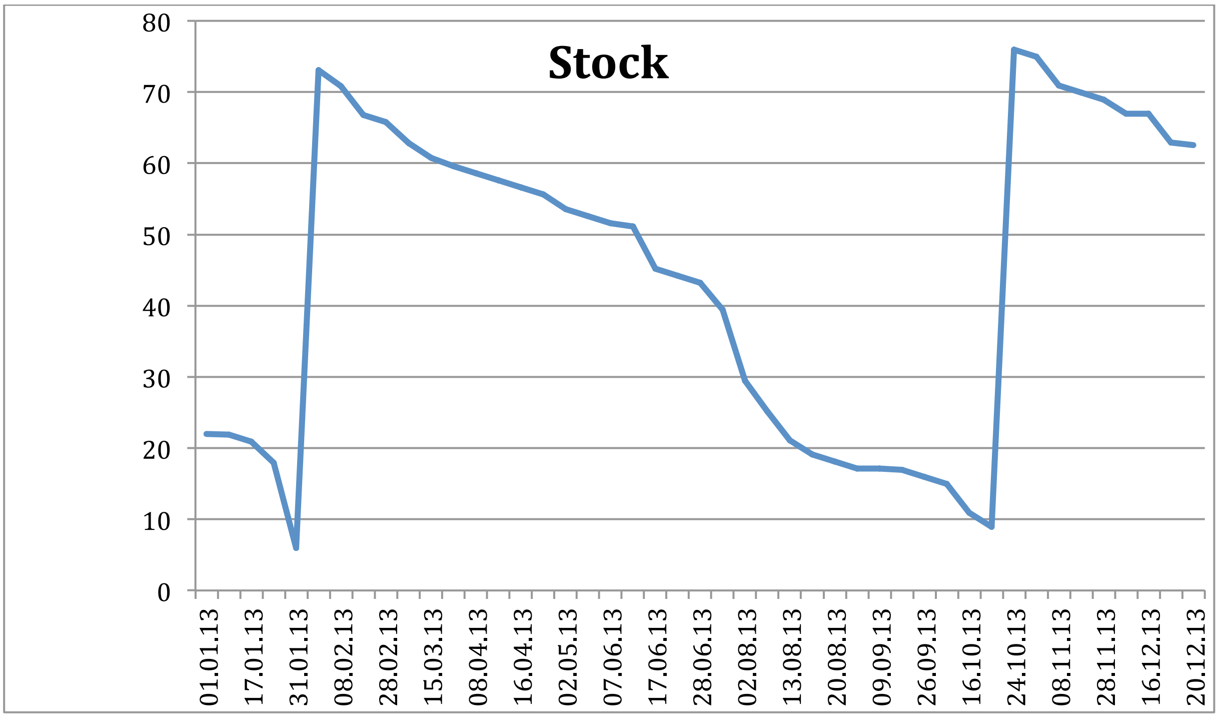
10.12.13
16.12.13
20.12.13

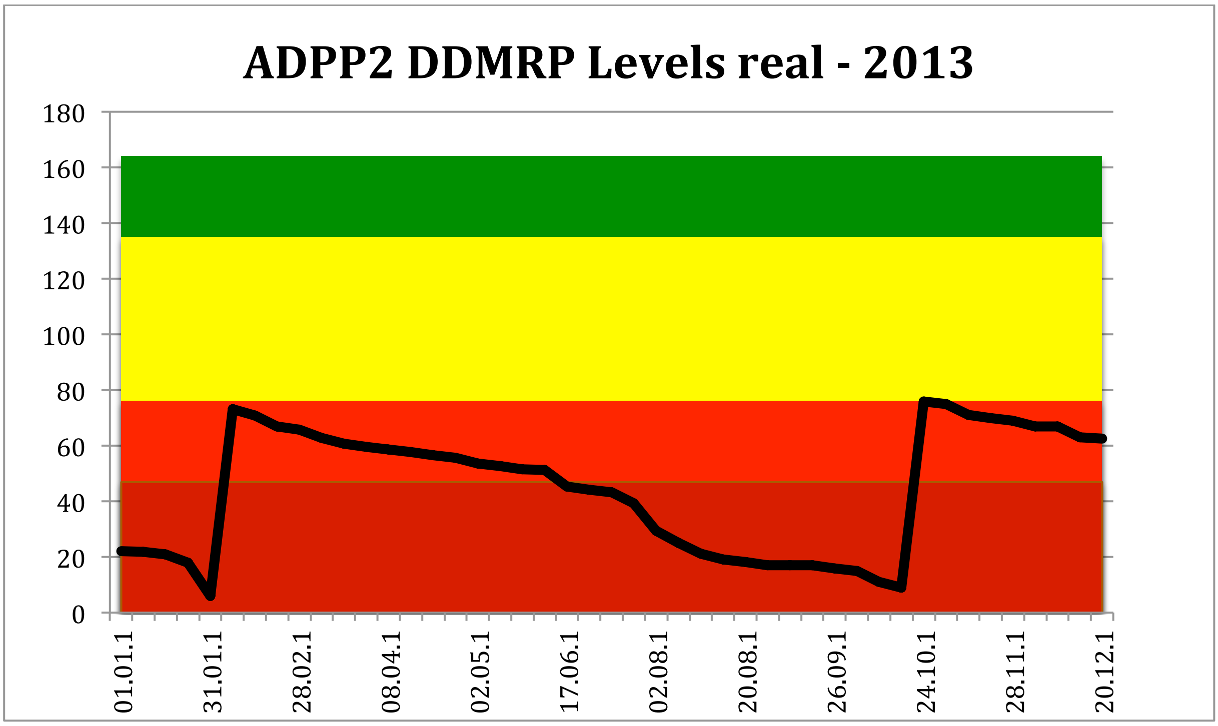

ADPP1 DDMRP Levels real - 2013
0
20
40
60
80
100
120
140
160
01.01.1
23.01.1
26.02.1
14.03.1
23.04.1
03.05.1
18.06.1
10.07.1
05.08.1
20.08.1
09.09.1
09.10.1
07.11.1
10.12.1
20.12.1

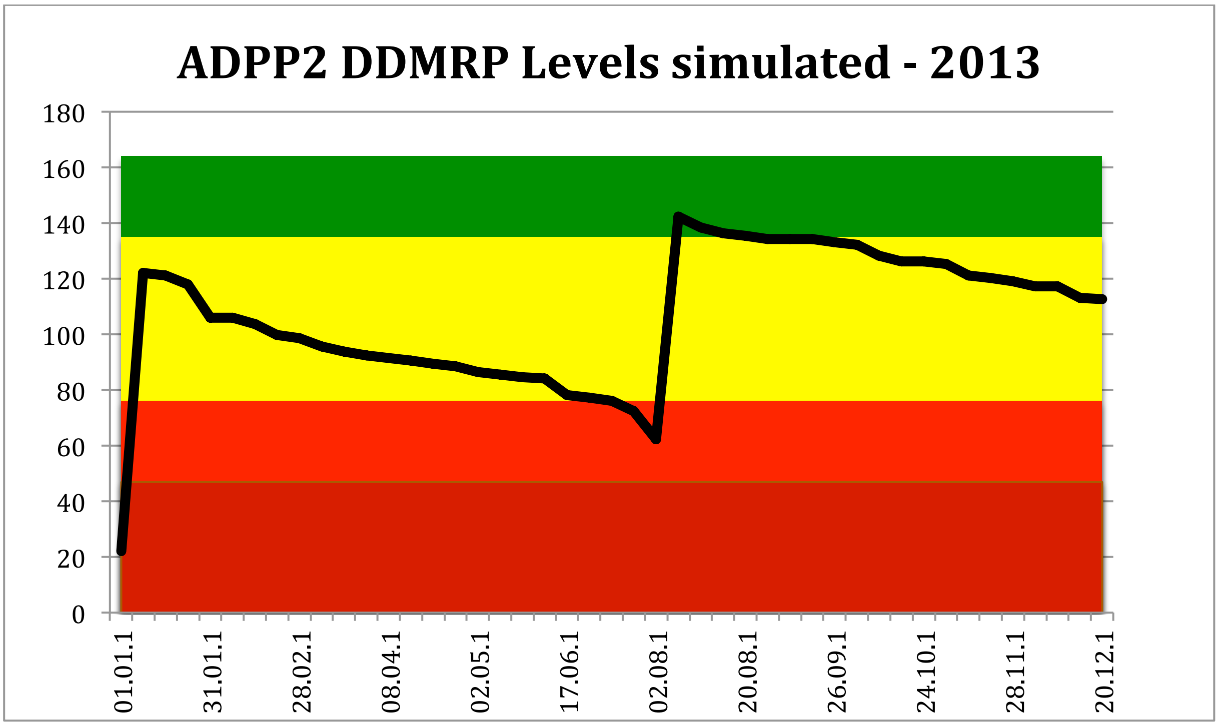


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	59	7	23	5	63
Simulation	59	15	6	1	82

ADPP2 1L

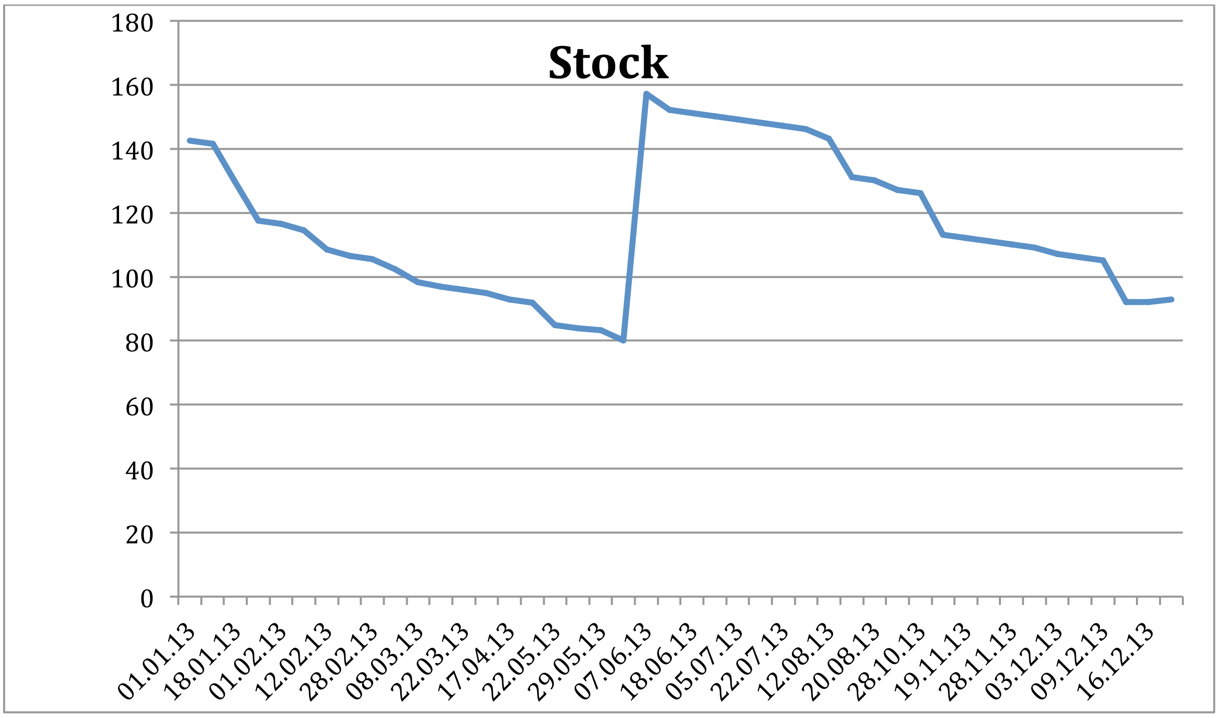

Stock
80
70
60
50
40
30
20
10
0
01.01.13
17.01.13
31.01.13
08.02.13
28.02.13
15.03.13
08.04.13
16.04.13
02.05.13
07.06.13
17.06.13
28.06.13
02.08.13
13.08.13
20.08.13
09.09.13
26.09.13
16.10.13
24.10.13
08.11.13
28.11.13
16.12.13
20.12.13

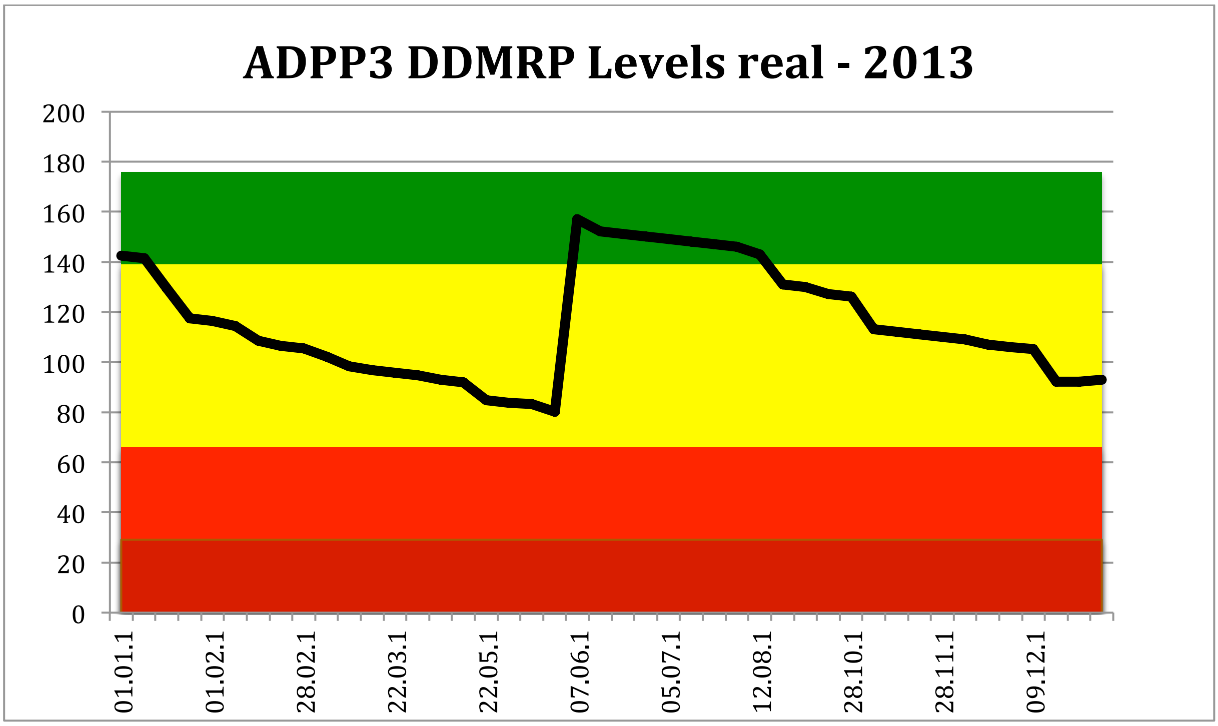

ADPP2 DDMRP Levels real - 2013
180
160
140
120
100
80
60
40
20
0
01.01.1
31.01.1
28.02.1
08.04.1
02.05.1
17.06.1
02.08.1
20.08.1
26.09.1
24.10.1
28.11.1
20.12.1

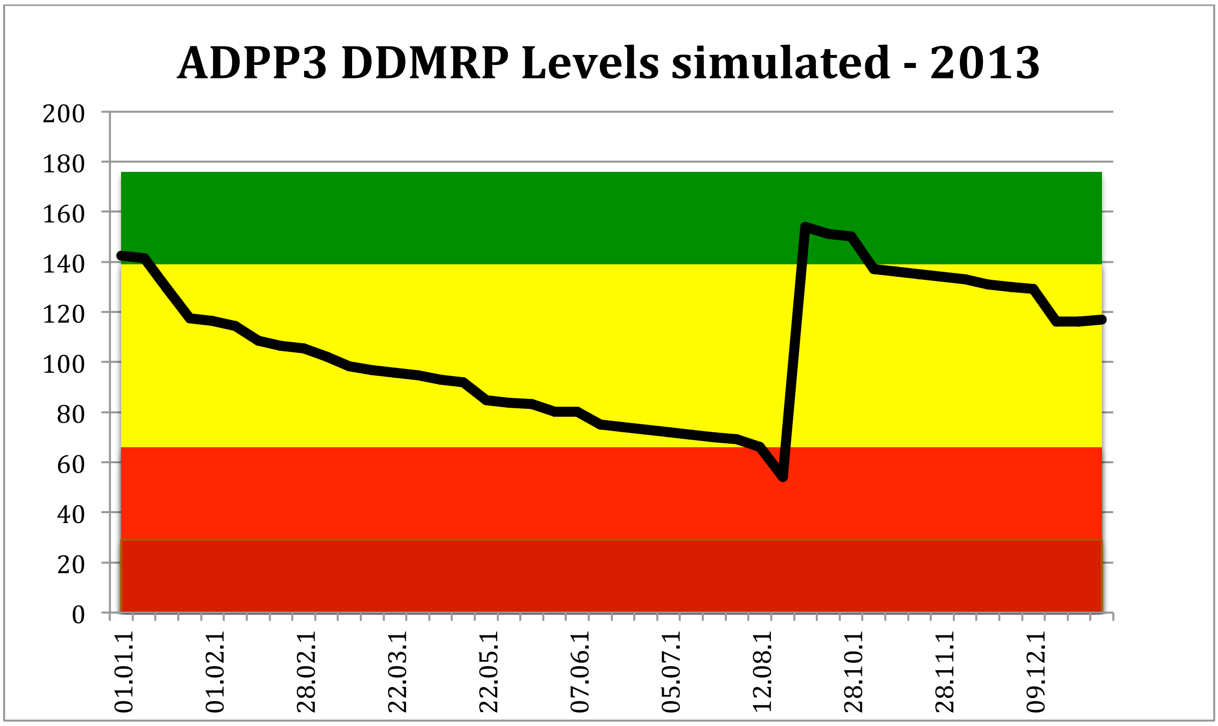


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	47	0	44	20	45
Simulation	47	4	2	0	108

ADPP3 1L

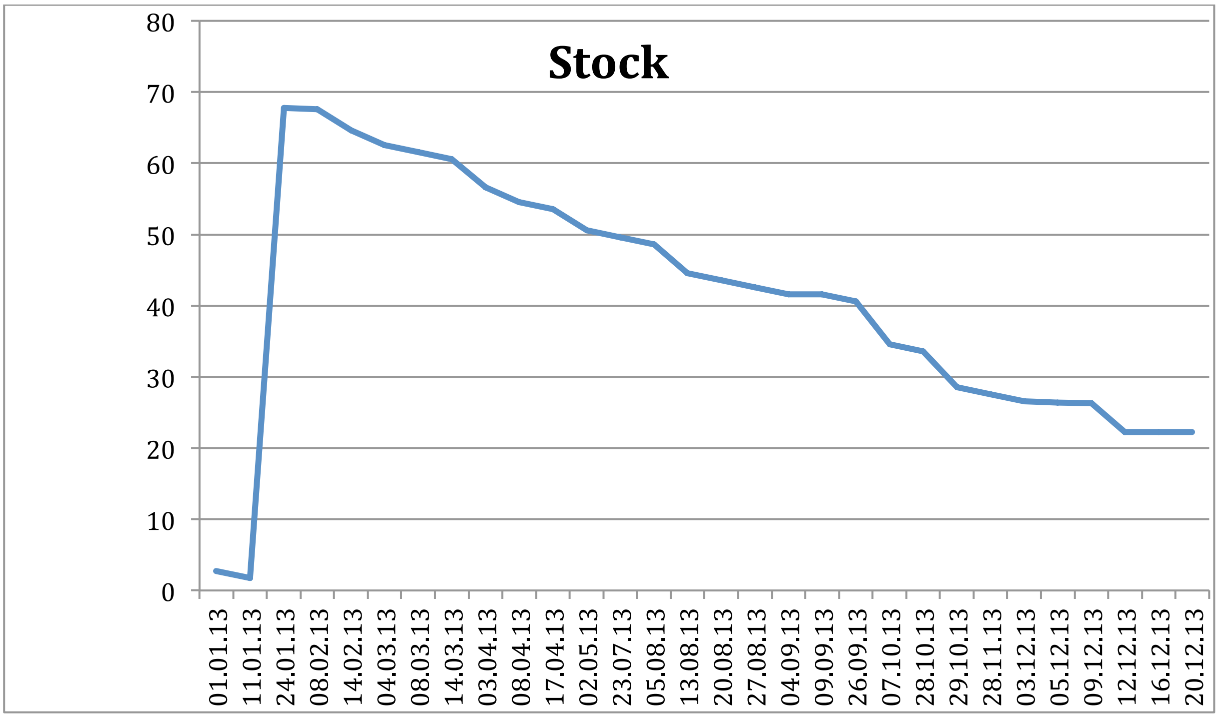

Stock
180
160
140
120
100
80
60
40
20
0
01.01.13
18.01.13
01.02.13
12.02.13
28.02.13
08.03.13
22.03.13
17.04.13
22.05.13
29.05.13
07.06.13
18.06.13
05.07.13
22.07.13
12.08.13
20.08.13
28.10.13
19.11.13
28.11.13
03.12.13
09.12.13
16.12.13


ADPP3 DDMRP Levels real - 2013
200
180
160
140
120
100
80
60
40
20
0
01.01.1
01.02.1
28.02.1
22.03.1
22.05.1
07.06.1
05.07.1
12.08.1
28.10.1
28.11.1
09.12.1



Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	46	11	0	0	116
Simulation	46	4	1	0	106

ADPP4 1L


Stock
0
10
20
30
40
50
60
70
80
01.01.13
11.01.13
24.01.13
08.02.13
14.02.13
04.03.13
08.03.13
14.03.13
03.04.13
08.04.13
17.04.13
02.05.13
23.07.13
05.08.13
13.08.13
20.08.13
27.08.13
04.09.13
09.09.13
26.09.13
07.10.13
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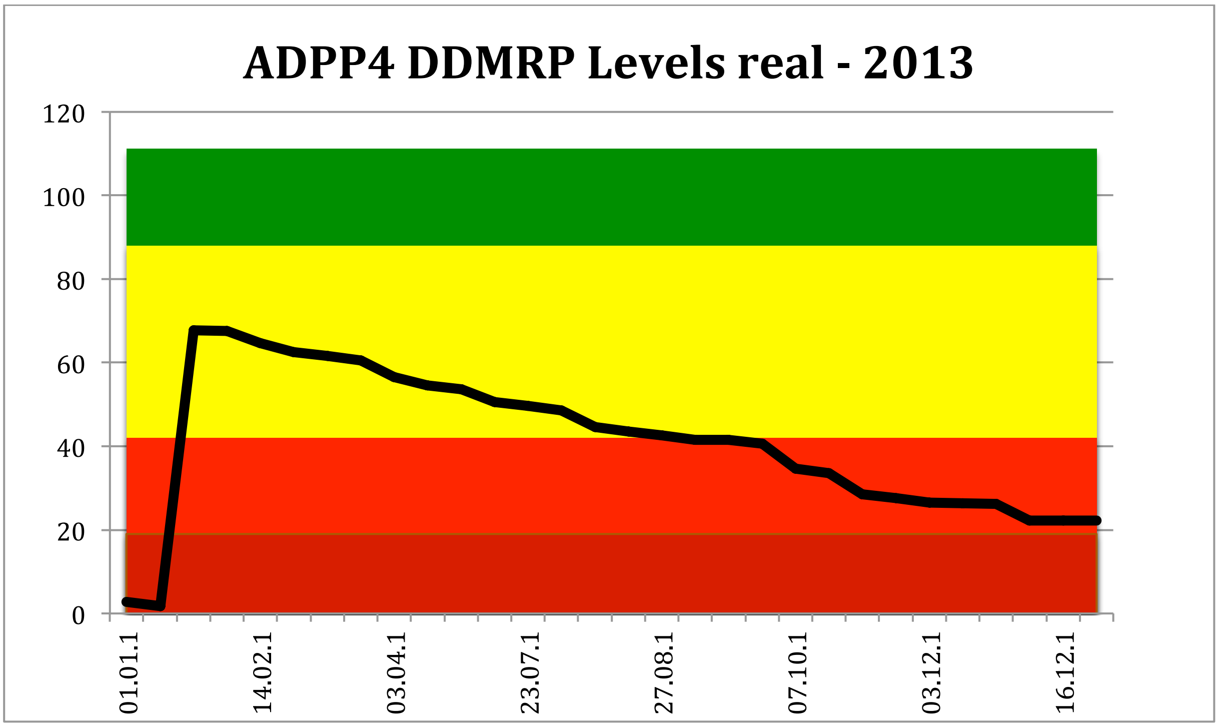
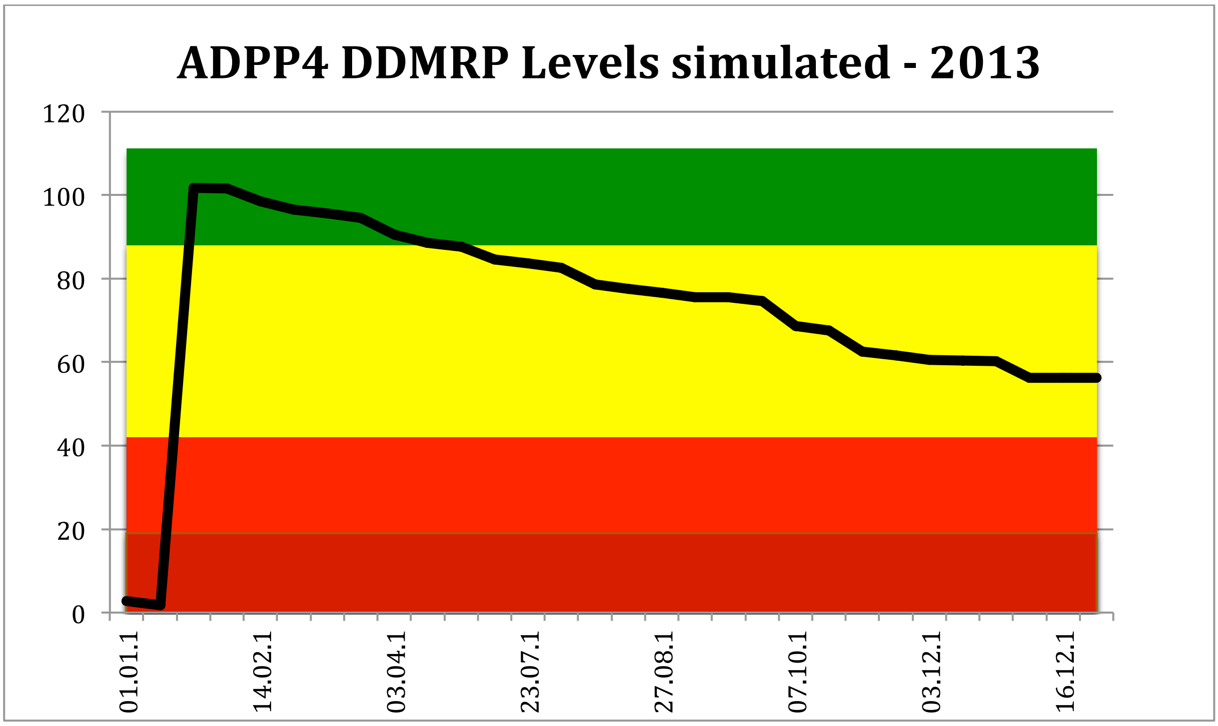
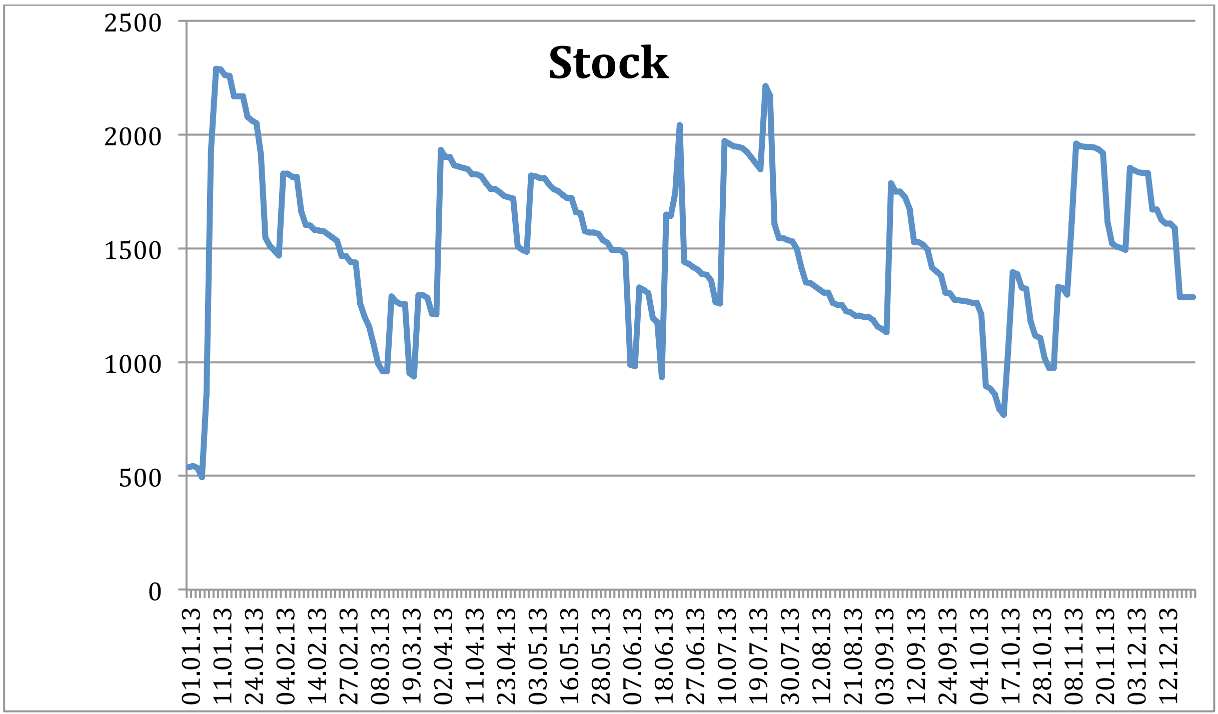
16.12.13
20.12.13

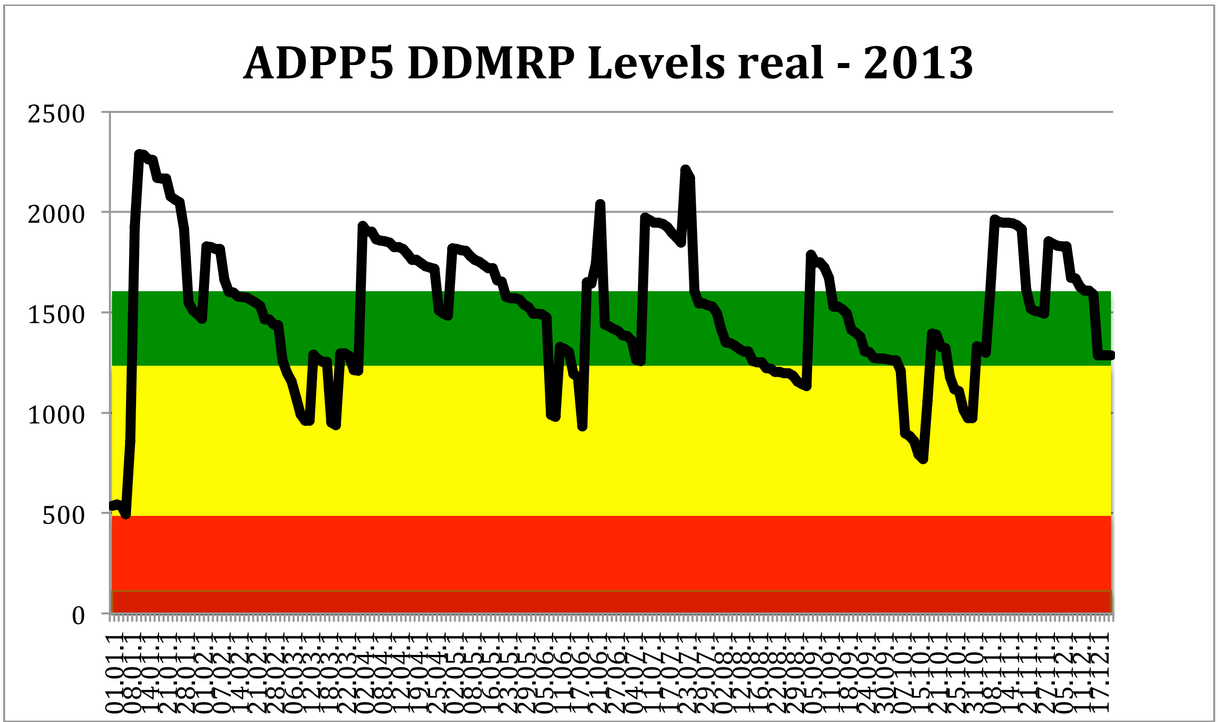

ADPP4 DDMRP Levels real - 2013
0
20
40
60
80
100
120
01.01.1
14.02.1
03.04.1
23.07.1
27.08.1
07.10.1
03.12.1
16.12.1

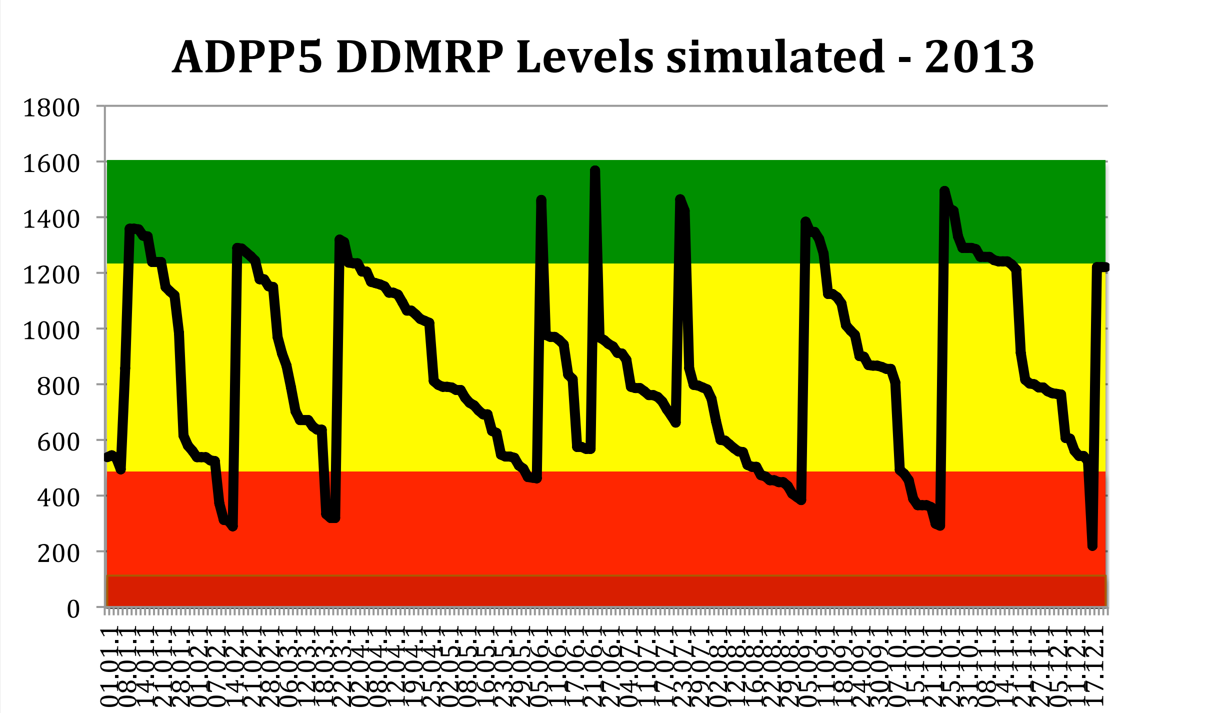


Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	32	0	14	1	42
Simulation	32	8	1	1	75

ADPP5 1KG


Stock
2500
2000
1500
1000
500
0
01.01.13
11.01.13
24.01.13
04.02.13
14.02.13
27.02.13
08.03.13
19.03.13
02.04.13
11.04.13
23.04.13
03.05.13
16.05.13
28.05.13
07.06.13
18.06.13
27.06.13
10.07.13
19.07.13
30.07.13
12.08.13
21.08.13
03.09.13
12.09.13
24.09.13
04.10.13
17.10.13
28.10.13
08.11.13
20.11.13
03.12.13
12.12.13


ADPP5 DDMRP Levels real - 2013
2500
2000
1500
1000
500
0



Source	# data entries	# High inv. alerts	# Low inv. alerts	# Stock outs	Average stock level
Reality	226	181	3	0	1511
Simulation	226	42	30	0	852