Redesign of Manufacturing Planning and Control Processes at AGI-Shorewood Van de Steeg

Master's thesis of P.F.A. van den Berg
Master of Science, Industrial Engineering and Management

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Author P.F.A. (Paul) van den Berg
Student Industrial Engineering & Management
Track: Production & Logistics Management
p.f.a.vandenberg@student.utwente.nl

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Organization AGI-Shorewood Van de Steeg
Lenteweg 8
7532 RB Enschede

University University of Twente
School of Management and Governance
Department of Operational Methods for Production and Logistics (OMPL)
P.O. Box 217
7500 AE Enschede

Project Initiator M. Bril
Managing Director

Company Supervisor C. Dankers
General Manager

University Supervisors J.M.J. Schutten
Assistant Professor
L.L.M. van der Wegen
Assistant Professor

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PREFACE

This master's thesis is the final result of my graduation project for the Master of Industrial Engineering and Management (IE&M) at the University of Twente. During the past eight months, I did my research in the planning department of AGI-Shorewood Van de Steeg (AVDS) in Enschede. It has been a powerful experience, which contributed highly to my set of personal and professional skills. This graduation project forms the end of the second of my two consecutive studies, Mechanical Engineering and Industrial Engineering and Management; during the last seven years, I have developed a solid basis of knowledge and skills.

I could not have written this thesis without the support of many people. First of all, I thank my supervisors from the University of Twente: Marco Schutten and Leo van der Wegen. Marco, thank you for your critical feedback, valuable suggestions, and attention to details, and Leo, thank you for your involvement, thorough feedback, and personal coaching style. The coaching, feedback, and time of the both of you have contributed greatly to the quality of my graduation project and thesis.

Of my colleagues at AGI-Shorewood Van de Steeg, I first thank my supervisor Chris Dankers for his guidance during the course of my project. Thank you for your insights and for stimulating me to initiate the planning project group and to involve a diverse group of people in my graduation project. Further, I thank Martin Bril for his visionary input, Hermen Nasette for his valuable knowledge, and the planners for their time, knowledge, input, and for letting me infiltrate their office: Martin Oosten, Jan Scharrenborg, and Frank Maasman. I thank AVDS's own IT-goeroe: Bert Hovenkamp. Thank you for your ideas and commitment. To the remaining members of the planning project group, thank you for your involvement and feedback.

I am much indebted to my family and in-laws for their support throughout my studies. I thank my parents for enabling me to study and for stimulating me to continue my personal and professional development at the University of Twente. I thank my father, father-in-law, brother and brothers-in-law for reading my early thesis chapters and for the discussions we had.

Finally, I thank Thea. Thank you very much for your love, support, encouragements, inspiration, endless patience, and for having faith in a successful ending of this graduation project. I could not have done it without you!

Paul van den Berg

Enschede, August 2012

Summary

Problem

The current economic crisis heavily affects AGI-Shorewood Van de Steeg's main market; this financial pressure creates a strong incentive to save costs and increase profits. AVDS has often, especially in busy periods, problems with shipping orders timely, and has basically two options in order to get a late order in time to the customer: (1) faster (and more expensive) transportation and (2) the use of more temporary personnel (to get the work done faster). AVDS spent in 2011 €70,000 on faster transport, and €635,500 on temporary personnel. We observed that the core problem was that AVDS had fragmented manufacturing planning and control (MPC) processes. So, if we redesigned the MPC processes in such a way that the MPC processes were no longer fragmented, the MPC processes would perform better and AVDS's delivery reliability would improve, while its costs on faster transportation and temporary personnel would reduce.

To tackle this problem, we formulated a main research question and a problem solving approach. We first focused on the current situation, to analyze how AVDS worked and performed. Then, we collected relevant literature and developed a redesign of the MPC processes at AVDS. The latter was done in cooperation with a planning project group, in which we involved the (key) stakeholders of the planning project, gathered their input and feedback, and created support for the implementation that was to come. Then, we constructed an implementation plan, a pilot plan, executed this pilot, and evaluated it.

Analysis of the current situation

We analyzed the current situation by meeting with many people and described the current MPC processes. Next to this, we focused on the KPIs that AVDS employs, and performed a shop floor data analysis to see how the manufacturing departments performed according to planning. The manufacturing departments finished many orders later than the internal due dates of the orders. For example, Printing finished in the first quarter of 2012, on average, 21.76%, 16.97%, and 1.74% of all orders late, more than 2 hours late, and more than 24 hours late, respectively. In this department, an order that was late, on average, was almost 12 hours late. We identified three causes that had the most influence on the performance of AVDS's manufacturing system in the shop floor data analysis: (1) the culture at AVDS is that operational performance is more important than planning, (2) capacity in Die Cut and Separating may be insufficient, and (3) set up times are long and highly sequence-dependent. The latter two were out of scope, so we focused on the former in developing our redesign.

Redesign of the MPC processes

Our redesign consisted of several steps. We focused on the order structure at AVDS, developed an MPC framework, fulfilled the separate parts of the framework, and briefly focused on KPIs. The order structure at AVDS lacked a vital type of order, the 'job'. For example, the current order structure caused inaccurate shop floor data. A job defines the exact composition of a set of physical materials and the processing required to fulfill it. A job is a unique identifier, which enables AVDS to trace back for a specific job, for example, which materials were used to manufacture it; this is known as traceability. The main part of our redesign revolved around an MPC framework that we developed; we suggested that AVDS uses this framework to position its planning-related processes and functions in the organization. We focused especially on four modules in the framework: (1) job planning and resource loading, (2) combination-making, (3) scheduling, and (4) shop floor control. Our redesign seated on two important principles: (1) planning is leading and (2) we freeze the planning beforehand. For the job planning and resource loading module, we determined that AVDS should keep using the concept of a combination (that is, merge different

orders to save on total set up time), but should introduce, the 'combination due date'. This prescribes when the combination must be finished. For the combination-making module, we defined the optimal combination and advised AVDS to make combinations more often than once per day. For the scheduling module, we proposed to use a hybrid central scheduling approach: central scheduling (Planning makes the schedule) enhanced with a feedback loop (manufacturing departments provide Planning with feedback on the quality of the schedule). We further recommended AVDS to use a rolling horizon for planning and scheduling (update future schedules at the end of each schedule period), and to freeze the schedule beforehand (make sure that a schedule is changed as little as possible during its execution). For the shop floor control module, we described a process to change a schedule once it is frozen; we made such a formal process to change the current culture of permissiveness. Finally, we briefly focused on the KPIs; we suggested that AVDS also uses KPIs that stimulate the performance with respect to planning.

Implementation plan

In constructing the implementation plan, we used the 8-step implementation roadmap of Kotter (1996). This roadmap consists of 8 steps, each tackling frequently made errors in changing organizations; the steps are, respectively, (1) establish a sense of urgency, (2) form a powerful guiding team, (3) create a vision, (4) communicate the vision, (5) empower action, (6) create short-term wins, (7) do not declare victory too soon, and (8) make change stick. The largest part of the implementation plan was the pilot, which forms a part of step 5. We constructed a plan for a pilot in the Printing department. It ran for three weeks. We kept track of all issues during the pilot and made a list of required changes to the information system (IS), we involved employees and the manager of the IS in this. At the end of the pilot, we analyzed the performance of the manufacturing departments to see whether implementing the redesigned MPC processes would improve performance. We used three performance measurement tools, (1) the shop floor data analysis, as we already used in analyzing the current situation, (2) the KPIs that AVDS had in place, and (3) the results of the registration forms, which we developed for use during the pilot. The results showed that, although the number of combinations that left Printing late did not decrease, the average lateness of orders decreased significantly (from 12 hours to 3.5 hours). This greatly reduced the severity of a late order. The productivity in Printing and Die Cut increased with 30% during the pilot, compared to the first quarter of 2012. The existing KPIs showed little improvement as these report on the external performance of AVDS's entire manufacturing system (there were operational issues in other departments during the pilot). From the results of the registration forms, we observed that the plan of the pilot was followed fairly accurate and that it was very important that the IS was changed quickly, in order to support the redesign.

Recommendations

Because the pilot showed good results, we recommend to continue with the implementation process, which we already initiated, of our redesign of the MPC processes at AVDS. When the IS is ready to support the new MPC processes, we recommend to expand the implementation horizontally to other departments. We further recommend to change the order structure, which means introducing the 'job' order type; this enables AVDS to use a unique identifier for each set of physical material through AVDS's manufacturing system, which improves shop floor data accuracy and also enables traceability. Very important though, is that AVDS's management actively steers and monitors the implementation. It must create support at every step by involving all the affected employees, and guard against declaring victory too soon: change only sticks when it becomes "the way we do things around here" (Kotter, 1996). If AVDS's management is able to successfully implement our redesign of their manufacturing planning and control processes, we expect AVDS to reduce its expenditures on extra transportation means and temporary personnel, while at the same time improving its delivery reliability and internal performance.

TABLE OF CONTENTS

EXPLANATION OF ABBREVIATIONS

AVDS	AGI-Shorewood Van de Steeg
ERP	Enterprise Resource Planning
IS	Information System
KPI	Key Performance Indicator
MPC	Manufacturing Planning and Control
RQ	Research Question

1. Introduction

This chapter aims to provide the reader with an introduction to this project; it introduces the company of AGI-Shorewood Van de Steeg (AVDS), the motives of this project, and the approach we follow. The structure of this chapter is as follows. Section 1.1 briefly introduces the company. Section 1.2 explains the motives of AVDS to initiate this project and formulates the problem statement. Section 1.3 formulates the research questions. Section 0 explains the structure of this thesis. Section 1.5 lists the deliverables of this project. The last section of this chapter, Section 1.6, introduces and defines some terminology, which we will use in the remainder of this thesis.

1.1 Company introduction

This section aims to introduce the problem owner; we keep this introduction short. See Chapter 2 for a comprehensive description of AVDS.

AVDS manufactures cardboard-based packaging and serves mainly European markets; the main clients are large and medium-large suppliers of audio and data carriers (that is, for example, CDs or DVDs), music publishing companies, movie studios, or game studios. Next to these traditional markets, AVDS currently strives to create a position as a producer of high-quality carton packaging in other new markets, such as personal care / cosmetics, lifestyle, and related markets. Currently, AVDS employs 110 employees and generates a turnover of approximately 20 Million Euros. A major portion (85%) of this turnover comes from export to various European countries. Generally, AVDS has a delivery period of 4-5 workdays for typical products, from order confirmation to physical delivery of the order at the customer.

1.2 Motives

This section discusses the main motives of this project and clarifies how these motives lead to the problem statement. It aims to explain what drives AVDS to initiate this project.

The current economic crisis affects the media sector heavily and this has severe financial consequences for AVDS. Several reorganizations were necessary for AVDS to adapt to the new economic situation. The financial pressure creates a strong incentive to save costs and increase profits; it also stimulates AVDS to develop activities in markets that are less affected by the economic crisis.

Delivery reliability is very important to the customer, but AVDS has often, especially in busy periods, problems with shipping orders timely. This causes unsatisfied customers and may prevent customers from placing new orders. The most important cause for late order shipments is that the internal due dates, set by the planning department, are frequently breached. An internal due date is the time at which a manufacturing department has to finish an order. When the department breaches such an internal due date, chances are that the next manufacturing department has to wait for the order and then, it may also breach its internal due date, causing a domino-effect. Warehousing and Shipping is the last department in the manufacturing process and strives to deliver the order to the customer in time, even if the previous department breached the internal due date. It can catch up lost time, for example by arranging faster, but more expensive, transportation. In 2011, Warehousing and Shipping spent roughly €70,000 on extra transportation costs, but still, on average, 2.6% of all orders arrived late at the customer (see Chapter 2). Without these means, delivery reliability would have been significantly worse. Another way to catch up lost time is to employ more temporary personnel. The departments Finishing and Hand Assembly regularly employ temporary personnel. However, this is costly. In 2011, AVDS spent €635,500 on temporary personnel in these two manufacturing departments, and although a large amount of this expenditure is inevitable (the work must be done) a part of it is caused by peaks and fluctuations in the workload in these manufacturing departments. If we can reduce the fluctuations in the workload, AVDS would need less temporary personnel to cope with high peaks in workload and still deliver in time. Hiring slightly less temporary personnel and reducing the use of extra transportation would be a real cost-saver.

As said, the most important cause of the poor delivery reliability is that many internal due dates are breached (for argumentation, see Chapter 2); this is also one of the causes of the fluctuating workload. An internal due date may be breached for many reasons, such as, disturbances arise during production (for example, a machine breaks down or a rush order comes in), or the production schedule is not good enough (maybe too much work was planned). This project focuses on the manufacturing planning and control (MPC) processes. MPC processes concern the planning, scheduling, and control of a manufacturing facility. The schedule, as it is currently used, prescribes which orders must be processed by a manufacturing department in a shift, and which resource group should process the order. Currently, responsibilities for the various aspects of the MPC processes (workforce planning, material planning, shift planning, etc.) are fragmented among multiple departments of AVDS. This high amount of fragmentation undermines the planner's authority to control the manufacturing system according to schedule, and undermines the importance of the internal due dates. Furthermore, the schedule does not provide proper insight in the current workload, this is especially in busy periods a big issue. This lack of insight also hinders the determination of realistic due dates and prevents active control, instead of the current reactive way of working, of the manufacturing departments.

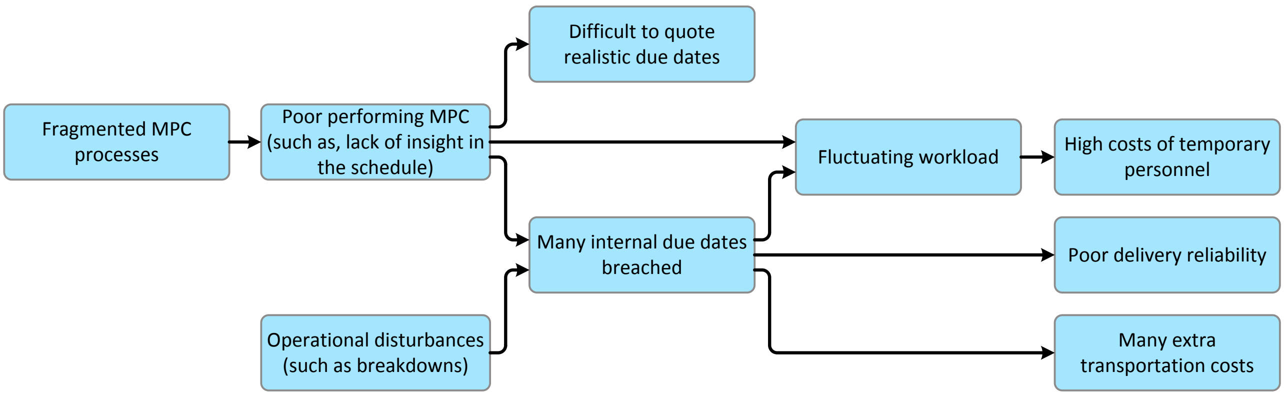


Figure 1: Problem bundle visualizing AVDS's motivation.

Figure 1 is a graphical representation of this discussion. It shows the major problems AVDS encounters. An arrow means that two problems have a causal relationship with each other. When, for example, problem A and problem B are connected by an arrow going from A to B, then problem A is a cause of problem B. When a problem has no incoming arrow, it is a so-called core problem. If we tackle a core problem, then this has a positive effect on other, related, problems (Heerkens, 1998).

Here, the core problems are the fragmented MPC processes and the operational disturbances. Every manufacturing system encounters operational disturbances, and tackling these disturbances requires often a pragmatic approach. Within AVDS, there are already several initiatives to reduce the amount and severity of operational disturbances in the manufacturing departments. So, we aim to tackle the *first* core problem, which describes that AVDS has very fragmented MPC processes, because AVDS never redesigned its MPC processes. Management of AVDS envisions that redesigning the MPC processes to create a comprehensive set of MPC processes, will result in better MPC processes.

If we redesign the MPC processes in such a way that the MPC processes are no longer fragmented, then the MPC processes should perform better, less internal due dates (set in the planning process) are breached, and ultimately, AVDS's delivery reliability will improve, while its costs on temporary personnel and extra transportation costs reduces. This leads us to conclude that AVDS needs to redesign its MPC processes. Management of AVDS recognizes the need for better defined MPC processes and wishes to have a redesign of these processes. Therefore, the problem statement, as below, focuses on the definitions (or the lack thereof) of the MPC processes.

Our problem statement is:

> *Currently, AGI-Shorewood Van de Steeg has not clearly defined its manufacturing planning and control (MPC) processes.*

If we want to solve this problem, we must describe how the MPC processes should look like. It is important though, that the solution focuses on centralized planning and control. The current fragmentation of the MPC processes results in a strong autonomy of the manufacturing departments; the planning department, which should have the overview of the workload of the manufacturing process, currently lacks authority to control the manufacturing departments sufficiently. Therefore, management of AVDS wants to centralize planning and control, to give the planners authority and overview, and to have the manufacturing departments focus on manufacturing. Management envisions that the authority and responsibility of planning and control should lie with one department.

So, we have the following restriction to the solution for our problem statement:

> *The redesign of the MPC processes must be based on a central planning philosophy.*

The solution to the problem statement should improve manufacturing planning and control processes and provide the planning department with sufficient authority to control the manufacturing departments. This will reduce the number of breached internal due dates. That reduction should improve delivery reliability, which will keep customers satisfied and thus generate extra sales, and a reduction in the extra transportation costs and costs of temporary personnel. So, redesigning the MPC processes is in line with the efforts to save costs and increase profits.

1.3 Research questions

The main research question further focuses the project; with it, we define what knowledge and answers we should have acquired at the end of the project. We use the problem statement, which we formulated in Section 1.2, to define the main research question. The objective is ultimately, to improve delivery reliability.

The main research question we have to answer is:

> *How should the MPC processes at AVDS be redesigned, based on a central planning philosophy, and implemented in order to improve delivery reliability?*

In order to answer the main research question, we define four research questions (RQs). The following four chapters in this thesis, Chapters 2 to 5, each discuss one of the four research questions. We define the RQs and discuss the main sources we use to answer each question below. Table 1 summarizes these sources.

Chapter 2: Current situation

The first step in the problem solving process is to analyze the current situation. So, the first research question focuses on analyzing how AVDS currently performs its MPC processes and how the manufacturing departments perform with respect to the planning.

RQ 1. How are the MPC processes currently organized at AVDS and how do the manufacturing departments perform?

To answer this RQ we use the knowledge of AVDS's employees and observe how the manufacturing process and the MPC processes perform from day to day. We refine these process descriptions, by having employees read and discuss them in group meetings (such as, within a planning project group). We also gather available information from the internal computer network.

Chapter 3: Literature

The next step is to gather required knowledge. So, the second research question focuses on acquiring relevant knowledge related to manufacturing planning and control.

RQ 2. What relevant knowledge, from literature, do we need to redesign the MPC processes at AVDS?

The main source for this RQ is scientific literature.

Chapter 4: Redesign of the MPC processes

The third research question synthesizes the knowledge we acquire in RQs 1 and 2. This is the core part of the project, because it aims at redesigning the manufacturing planning and control processes of AVDS. We create a fit between the literature and AVDS.

RQ 3. How should the MPC processes at AVDS be redesigned, based on a central planning philosophy, in order to improve delivery reliability?

The main sources are the our ideas, the information from the first two RQs, observations, and contributions and input from AVDS's employees.

Chapter 5: Implementation plan

The last phase considers the implementation plan of the proposed redesign of the MPC processes. We develop a plan for implementing the redesigned MPC processes.

RQ 4. How should AVDS implement the redesigned MPC processes?

To answer this RQ, we use literature to develop an implementation roadmap. We also observe, draw from our own ideas, and involve employees in the problem solving process.

	Observations	Knowledge of people	Our ideas	Internal network	Scientific literature
RQ 1	x	x		x	
RQ 2					x
RQ 3	x	x	x		x
RQ 4	x	x	x		x

Table 1: Main sources in answering the research questions.

1.4 Thesis structure

This section describes the structure of this thesis, as visually presented by Figure 2. It shows the relation between the research questions and the various chapters in this thesis.

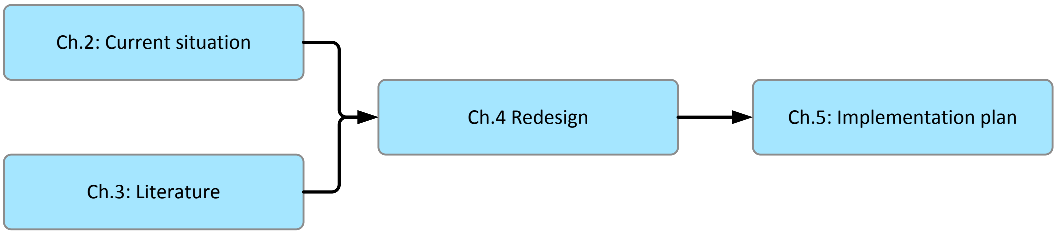


Figure 2: Thesis structure.

Chapters 2 and 3 provide us with the necessary knowledge by answering RQ 1 and 2, where Chapter 2 describes the current situation and Chapter 3 discusses relevant literature. Then, Chapter 4 synthesizes this knowledge and proposes a redesign of the MPC processes to answer RQ 3. Finally, Chapter 5 builds upon the redesign by suggesting how the implementation should take place.

1.5 Deliverables

We now know what the research questions are and how the structure of this thesis looks like. We can now list the deliverables; this project will deliver the following products:

- a description of the current MPC processes,
- an analysis of the current performance of the manufacturing departments, with respect to planning,
- a literature study,
- a redesign of the MPC processes,
- an implementation plan, and
- a master's thesis, containing the above products.

1.6 Definitions

Before we continue to Chapter 2, we focus on some terminology. We do this to clarify the terms we will use in the remainder of this thesis, because many different terms exist and often, they are used differently.

2. Current situation

In Chapter 1, we introduced the problem and constructed a research approach. This chapter concerns the first research question; we analyze the current situation at AVDS.

Section 2.1 describes the company AVDS, Section 2.2 explains how AVDS currently performs its MPC processes, Section 2.3 gives an overview of some of the relevant Key Performance Indicators (KPIs) that AVDS employs, and Section 2.4 analyses shop floor data to gain insight in how AVDS performs according to the planning.

2.1 Description of the company

This section forms the starting point for the analysis of the current situation at AVDS. Before we discuss the MPC processes in Section 2.2, we introduce AVDS in this section.

AGI-Shorewood Van de Steeg (AVDS) started over 80 years ago as a typical family business and is located in Enschede; it is part of the global AGI-Shorewood group, a major player in the packaging industry. In a series of steps, the company has evolved from a traditional printing office to a producer of high-quality carton-based packaging. AVDS's main customers are suppliers of audio and data carriers, music publishing companies, movie studios, or game studios; these are usually European customers. To be less dependent of the economical results in the media sector, AVDS strives to create a position as a producer of high-quality carton-based packaging in other new markets, such as personal care or lifestyle. AVDS generates a turnover of approximately 20 Million Euros, which is mainly due to sales in other European countries than the Netherlands, and employs 110 employees. Generally, AVDS has a (very short) delivery period of 4-5 workdays from order confirmation to physical delivery of the order at the customer. AVDS distinguishes itself from its competitors by providing a complete packaging solution, from packaging design to printing and final assembly.

Sections 2.1.1 through Section 2.1.4 discuss specific aspects of AVDS, that is, respectively, its products, the seasonal character of demand, the organizational structure, and the general manufacturing process.

2.1.1 Products

There is a wide variety in AVDS's product range. Still, we distinguish two main categories: media and non-media packaging. See Figure 3 for an impression of the product range.

Figure 3: An impression of the product range of AVDS (AGI-Shorewood Van de Steeg, 2012)

First, there is the media packaging; this concerns packaging for various data carriers (for example, CDs or DVDs). Differences between products are, for example, the number of trays in the product, the number of pages and whether or not the trays are stacked (the upper right quadrant of the left column in Figure 3 shows a product with a so-called tray stack). Second, AVDS has non-media packaging. These products are relatively new to AVDS and developed in close cooperation with the customer, often in new markets, for example, gift card or personal care packaging. At the moment, roughly 5% of AVDS's turnover comes from sales related to non-media products.

2.1.2 Seasonality of demand

Especially in the media market, there is a strong seasonal demand pattern. Many media releases are in November or December. So, for AVDS, this results in high monthly demand in August to November, because the largest part of its turnover comes from customers in the media market. Figure 4 shows the number of products that AVDS produced per month in 2011.

Traditionally, AVDS distinguishes two seasons, high and low season. High season is in the months August, September, October, and November; low season is from December to July.

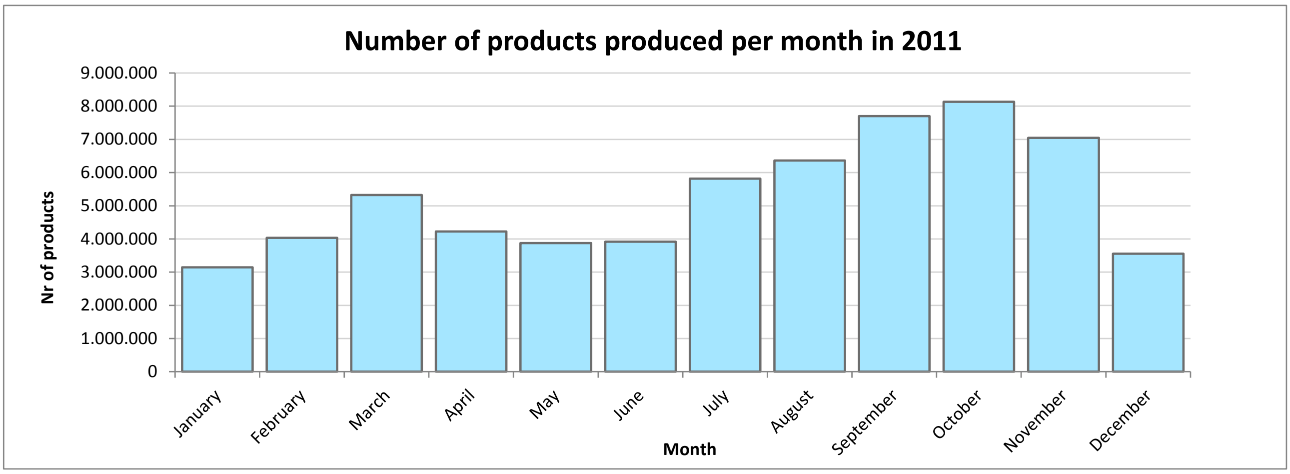


Figure 4: Number of products produced per month in 2011 (from internal network).

2.1.3 Organizational structure

The organizational structure of AVDS (see Figure 5) is very flat; there is little hierarchy in the company and the atmosphere is very informal. Operations performs the main part of the physical manufacturing process, that is, from order confirmation to the delivery to the customer. Commerce keeps contact with the (potential) customers and is responsible for generating revenue by performing sales and marketing activities. Finance is responsible for activities such as, accounting, human resource management, administration, and information technology (IT). KAM is the department responsible for monitoring the quality delivered by the manufacturing system, ensuring the safety of all personnel, and dealing with environmental issues. Finally, management is responsible for supervising AVDS and setting long-term objectives; the management secretary supports management.

AVDS uses an information system (IS) to collect and manage all data that the (manufacturing) departments produce. An IS stores, retrieves, transforms, and disseminates information in an organization, in order to support the business operations and managerial decision making (O'Brien & Marakas, 2009).

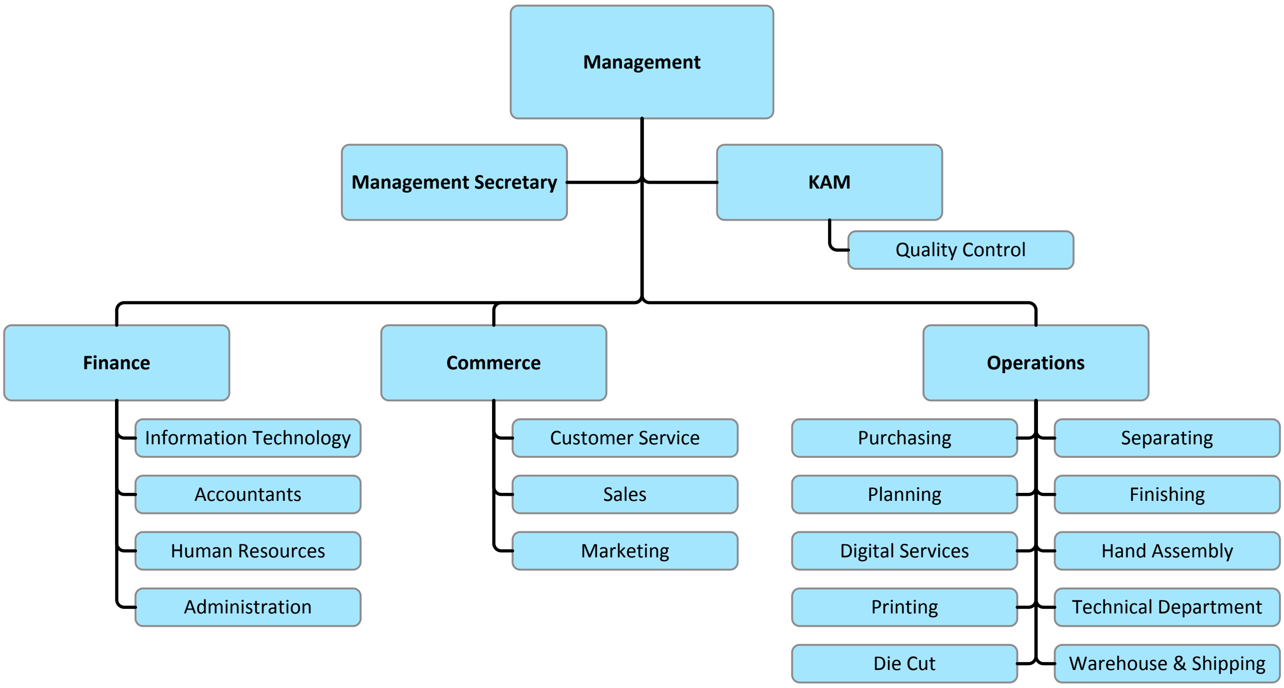


Figure 5: Organizational chart of AVDS.

Shift work

Several manufacturing departments work in multiple shifts per day. Planning and Digital Services work all year long in two shifts, Printing and Die Cut work all year long in three shifts, and Finishing works in either two shifts (in the low season) or three shifts (in the high season). The rest of the departments work regular business hours.

Planning department

The planning department plays an important role in the MPC processes. Currently, the planning department consists of 3 planners. Not every planner is involved with the planning and control of every manufacturing department. Two planners are responsible for the first part of the manufacturing process: Printing, Die Cut, and Separating. The third planner is responsible for the last part: Finishing and Hand Assembly. The reason for dividing responsibilities in the planning department results from characteristics of the manufacturing process; Printing, Die Cut, and Separating work with combinations (that is, a combination of orders, as we will discuss in Section 2.2) and Finishing and Hand Assembly work with individual orders. Additionally, the two planners, responsible for Printing, Die Cut, and Separating, also have to make the combinations (again, see Section 2.2).

Manufacturing departments

The manufacturing departments are the departments involved in the physical manufacturing process; these are Printing, Die Cut, Separating, Finishing, and Hand Assembly. Each of these departments utilizes resources (such as machines and personnel (Pinedo, 2009)) to perform a specific part of the manufacturing process.

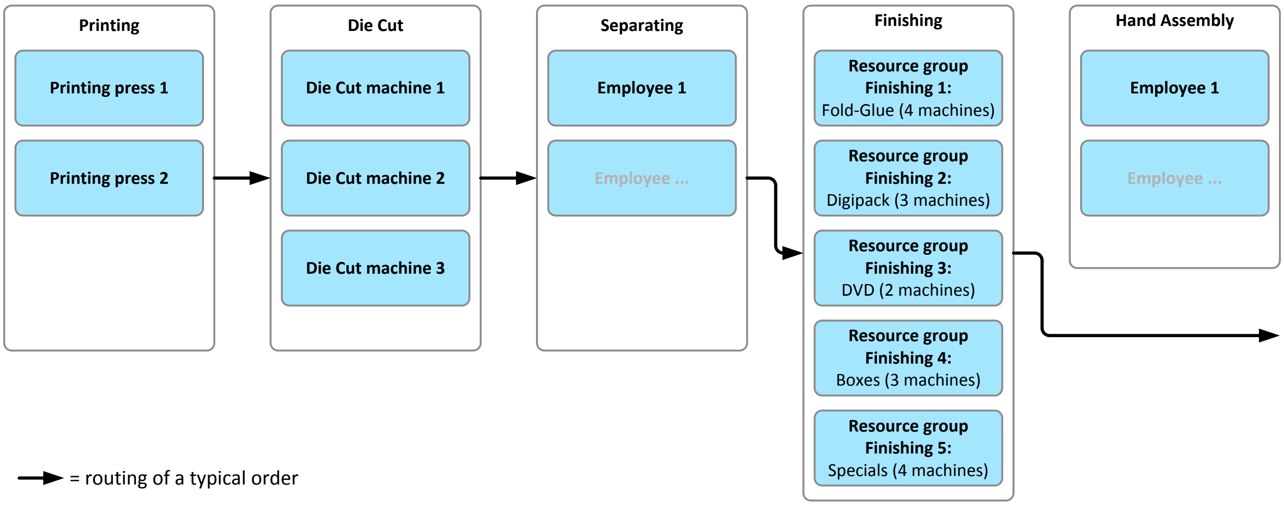


Figure 6: Resources per manufacturing department.

Figure 6 gives an overview of the resources in each manufacturing department, where the arrow depicts the routing of a typical order. We see that Printing uses 2 printing presses and Die Cut uses 3 die cut machines. Separating however, uses no machines, because the work is difficult to automate; usually 1 employee works in the Separating department. Finishing uses 16 machines in 5 resource groups to finish the products (for example, folding or glueing); every resource group has specific capabilities, but machines within a resource group have roughly equal capabilities. Machine group 1 (folding and glueing), 2 (Digipack), 3 (DVD), 4 (boxes), and 5 (specials) consist of 4, 4, 3, 2, and 3 machines, respectively. Hand Assembly uses no machines and the number of employees that work on the department depends on the amount of work available; these employees are mostly temporary workers.

2.1.4 General manufacturing process

The exact routing through the manufacturing process is product specific, but most orders follow more or less the same general routing through the various manufacturing departments. See Figure 7 for the general manufacturing process. Every order has a routing, which describes the specific route through the various manufacturing departments.

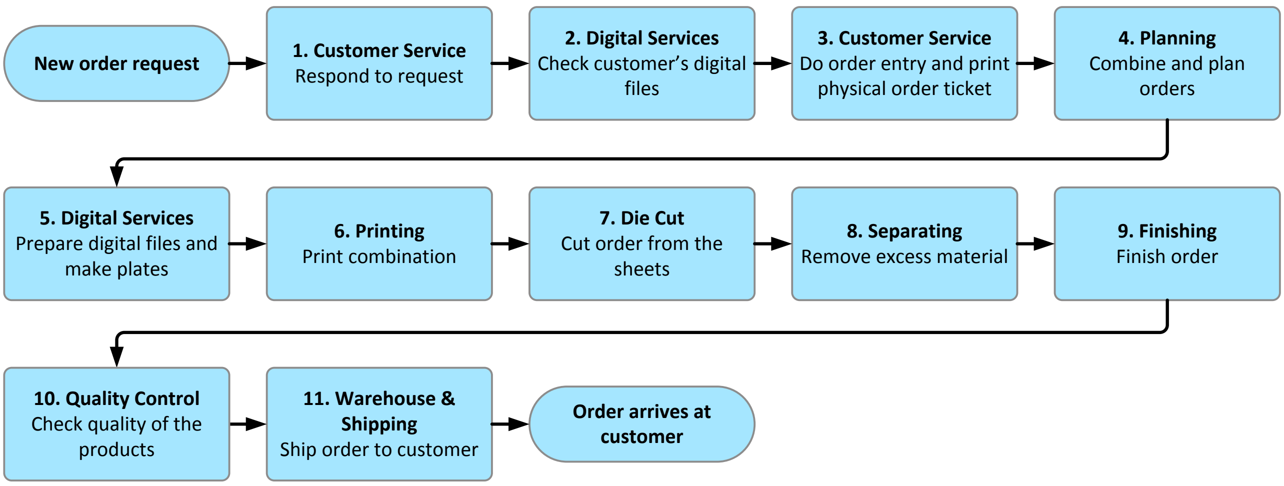


Figure 7: General manufacturing process at AVDS.

A typical order traverses the following path through AVDS's manufacturing system. Customer Service is the first department that comes into action when receiving an order request by a customer. Basically, it responds to the request of the customer, this may include, for example, a check for technical feasibility, a price quotation, or a delivery date quotation (in cooperation with the planning department). Upon confirmation, the routing is fixed, the customer sends the final digital files (the artwork of the order), and Digital Services checks these. Customer Service then processes the order and adds it to the IS. Now, the order arrives (as a physical order ticket, see Appendix F) at Planning. Planning combines the order with other orders and determines the internal due dates (that is, when every process step in the routing must be finished). We now speak of a *combination* instead of an *order* (we discuss this later on), and Digital Services prepares the digital files of the combination and makes the plates required by the Printing department. Printing now prints the combination on sheets of carton and Die Cut cuts the contours of the products in the sheets of paper. Separating removes the surplus material and separates the combination into the original orders. So, we now speak of orders again. Finishing performs the last actions required (for example, folding, glueing, placing trays, etc.). Quality Control checks the quality of the products and Warehouse & Shipping ships the order to the customer.

The distinction between orders and combination is a complicating factor when planning the manufacturing departments. Digital Services, Printing, Die Cut, and Separating work with combinations; Finishing, Quality Control, and Warehouse & Shipping work with the individual orders.

Here, we described the *general* manufacturing process. However, it may be interesting to look at the manufacturing process in more detail. To this end, Appendix A contains a flowchart of the *detailed* manufacturing process; this flowchart describes every step and decision in the manufacturing process. The flowchart also gives more insight in when AVDS speaks of an order and when of a combination. To construct this flowchart, we involved a various group of people to discuss, adjust, and improve the detailed manufacturing process flowchart.

2.2 Manufacturing Planning and Control processes at AVDS

This section explains how AVDS currently performs its manufacturing planning and control (MPC) processes. We decompose the MPC processes into several subjects, with which we structure this section. As we extensively use terminology related to the durations of various activities, we define set up time, processing time, and lead time as follows.

Set up time =	*The amount of time that is needed to reconfigure or clean a machine between orders (Pinedo, 2009). If the length of a set up depends on both the job just completed and on the one about to be started, then set up times are* sequence-dependent.
Processing time =	*The amount of time an order has to spend on a machine (Pinedo, 2009); in other words, solely the amount of time needed to produce the order, disregarding, for example, set up time.*
Lead time =	*The amount of time allotted for production of an order in a specific production stage in the routing of the order (Hopp & Spearman, 2008). Includes set up and processing time, but excludes the amount of time the order has to wait before processing.*

2.2.1 Delivery date quotation

Every new order requires a delivery date, which Customer Service communicates to the customer. AVDS has agreements with several large customers on a fixed delivery period; which is, usually, 3-5 workdays. The delivery date is then the day of order placement plus the delivery period; however, Customer Service still contacts Planning to come to a *realistic* delivery date. When such a customer places an order before

15:00, that same day counts as the first day of the delivery period. Of all orders, roughly 50% has such a fixed delivery period; for the remainder of the orders, the delivery period is at least 5 workdays.

2.2.2 Workload planning

Planning uses an Excel sheet to do workload planning for the departments Printing and Die Cut (see Appendix B). This workload planning is the determination of the planned workload (all planned orders) per shift and per department. In the Excel sheet, all expected set up and processing times of the planned orders in that shift are summed, and the planned workload is represented as a percentage of the available capacity in that shift. The number of shifts and available personnel determine the available capacity per shift and per manufacturing department. The planners use this workload and the particulars of the individual orders to determine realistic delivery dates.

2.2.3 Process planning

Process planning consists of two elements, determine the routing of an order and estimate what the processing times will be in every manufacturing step.

A *routing* describes the (sequence of) production steps required to produce the order; only for the Finishing department, the routing specifically describes which machine(s) should be used to produce the order. A routing also prescribes how many products need to be produced at every production step (to account for losses due to, for example, set ups), to make sure that a sufficient number of products exits the manufacturing process. Every order has a *default routing* and an *alternative routing*; this allows for more flexibility in balancing the workload. The default routing describes the routing that the order will follow under normal circumstances, but when disruptions occur, an order might follow the alternative routing.

Planning estimates the run speed (and thus the processing time) for the Finishing department. The run speed depends heavily on the type of product and the product's particulars. For the Printing, Die Cut, and Separating departments, Planning uses (predetermined) average set up times and run speeds. For Hand Assembly, Planning bases the estimation of run speed on an available capacity of 4 employees. This may be true for many orders, but the actual number of employees working on an order, may be (significantly) higher (or lower) than 4. The planner estimates the run speeds based on his own experience and in cooperation with the manufacturing departments and Customer Service.

2.2.4 Making combinations: orders vs. combinations

This section discusses combinations; these play an important role in the manufacturing process at AVDS, so we give a detailed explanation of the subject. First, we explain what a combination is and why AVDS makes combinations. Then, we focus in separate subsections on the optimal combination, the combination-making process, and the restrictions on making combinations, respectively. Currently, AVDS has no procedures on the combination-making process. The planners use restrictions to determine which orders may be combined, but these are in their heads; no document describes how to make combinations.

AVDS merges orders and forms so-called combinations; a *combination* is a set of orders that is grouped together on one sheet. The departments Digital Services, Printing, Die Cut, and Separating work with these combinations, instead of individual orders. AVDS makes combinations to reduce the total number of set ups (and thus, the total setup time) and the number of required plates for the printing presses (an offset lithography press, which AVDS uses, requires per combination, a plate for every color in the combination (Kipphan, 2001)). The reduction of the number of set ups is the main driver to make combinations, because in 2011, the total set up time accounted for 45% in the Printing and 40% in the Die Cut department of all manned hours (from internal document). Digital Services and Separating have no set up time.

In the Printing department, a typical combination needs 3,250 sheets to be printed, and on average, the 2 printing presses have a capacity of 6,000 sheets per hour. With these averages, we calculate the average run length to be 33 minutes ($\frac{3250}{6000}$ x60=33). An average set up takes 45 minutes. In the Die Cut department, a typical combination needs 2,700 sheets to be cut, and on average, the 3 die cutting machines have a capacity of 3,100 sheets per hour. The average run length is 52 minutes and an average set up takes 39 minutes. This means that, for a typical combination, the set up time contributes for 58% ($\frac{45}{45+33}$ =0.58) of the total lead time in the Printing and 43% ($\frac{39}{39+52}$ =0.43) in the Die Cut department. We see that the previously mentioned internal document reports slightly different percentages, this is because our calculation is based on one typical combination and the internal document on all actual production data from 2011.

By merging as many different orders as possible into a single combination, the number of set ups decreases and the average number of sheets in a combination increases. Because the machines have a large capacity and require long set up times, making combinations results in a total lead time reduction.

The optimal combination

So, what is 'the best possible combination'? We define the optimal combination below.

> *A combination is perceived as optimal if it contains many different orders, it has little unused surface on the sheet, and it approaches the required number of products in each order as close as possible.*

The above definition consists of 3 different aspects. The *first* aspect is the number of orders in a combination; as many as possible is best, then we save the highest number of set ups. For example, if we have 4 orders in a combination, then we have 1 set up, but if we print the 4 orders separately, then we have 4 set ups. So, by combining the orders, we save 3 set ups. The *second* aspect is the total unused surface on the sheet. All unused surface on a sheet is waste, this means that we throw away material (such as carton and ink) and time. By minimizing the unused surface on a sheet, we directly reduce the amount of waste. The *third* aspect focuses on the required number of products in each order in the combination. Each order requires a specific number of products; it is unacceptable to send fewer products to the customer than ordered. To calculate the number of products that we will end up with, we multiply the multiplicity of the order (the number of times that the order fits on a sheet) with the number of sheets to print minus the number of products consumed by the manufacturing process (that is, for example, products required for set ups and products with inadequate quality). For a potential combination, we can calculate for each order how many sheets need to be printed, in order to end up with a sufficient amount of good products. However, if we have more products than we need, the surplus will be thrown away. If we have multiple orders in a combination, then we need to print so many sheets, such that we end up with (at least) the required number of products for all orders. For example, a combination consists of 2 orders, where order 1 requires 2,200 products and fits 2 times on the sheet (a multiplicity of 2), and order 2 requires 3,000 products and has a multiplicity of 3. Then, for order 1, we need to print 1,100 sheets, and, for order 2, we need 1,000 sheets (we ignore set ups, etc.). We must print the maximum of the two values, which is 1,100 sheets. This results in 2,200 products for order 1 and 3,300 products for order 2; we have 300 products of order 2 too many. So, the third aspect aims to approach the required number of products in each order as close as possible.

However, the optimal combination is not optimal if the delivery date of the orders is jeopardized. Some orders have plenty of time before the delivery date, but when we combine this kind of order with an order that has little time before the delivery date, then we put more (or even too much) time pressure on the manufacturing departments. So, we strive to have the best possible combinations, but *within* the context set by planning!

Basically, the above discussion comes down to the following.

> *A good combination consists of as many orders as possible with the least amount of waste, without putting unnecessary or too much time pressure on the manufacturing departments.*

The combination-making process

The department that is responsible for the combination-making process is Planning. The planners make the combinations from all new orders that have to be produced. They use multiple restrictions to determine which orders to combine. The combination-making process is not automated: the planners determine which orders form a combination. The planners use the physical order tickets (see Appendix F) and an application in the IS (see Appendix D) to gather all information about the orders and create the combinations. Planning wants to make the best possible combinations; to be able to do this, it needs a sufficient amount of available orders. This means that Planning tends to wait as long as possible before making the combination. As customer orders – which require processing that same day – may come in until 15:00 (see Section 2.2.1), Planning waits until 15:00 before making the combinations; in this way, it has all the orders of that day.

The combination-making process is as follows. First, before the actual combination-making takes place, new orders that need to be combined come in. Then, after 15:00, Planning makes the combinations. When a combination is made, then Digital Services combines the digital files of the orders in the combination and produces the plates, required for printing the combination. Finally, Printing starts the physical manufacturing of the combination.

Making combinations usually takes 1-2 hours; this means that Digital Services can start processing the new combinations between 16:00 and 17:00. It has then 5-6 hours of available working time remaining in that shift to process the combinations. Planning causes a highly fluctuating workload in the Digital Services department by waiting until 15:00 to make the combinations. A combination needs to be processed at Digital Services before the shift, in which the combination is processed at Printing, starts.

Restrictions

Planning uses hard and soft restrictions to make the combinations; hard restrictions are binding and soft restrictions are not binding. If a hard restriction is violated in a potential combination of two orders, then this combination cannot be made. The hard restrictions are mostly of a technical nature. If a soft restriction is violated in a potential combination, then the combination may still be made, but it is not optimal.

A hard restriction is, as said, binding. These restrictions are:

- the carton must be of the same type,
- the coating must be of the same type,
- the required inks must be the same, and
- optional outsourcings must be the same.

If orders must be printed on different types of carton, or the required coating is different, then the orders cannot be combined. Each order requires certain colors of ink (cyan, magenta, yellow, or black), and some orders even require the use of specifically blended inks, that is, PMS inks; the required inks also form a hard restriction, if an order requires a specific PMS ink, then this cannot be combined with an order without it. The last hard restriction concerns outsourcing; if an order will be outsourced, then it cannot be combined with orders that will not be outsourced to this specific third party. These hard restrictions result from the characteristics of the orders.

The soft restrictions follow from the definition of an optimal combination. The less the soft restrictions are violated, the better the combination. The optimal combination is rare, actual combinations will always violate one or more restrictions. The soft restrictions are:

- as many as possible different orders in a combination,
- no unused surface on the sheet,
- no surplus products (due to differences in multiplicity and required number of products), and
- no unnecessary time pressure on the manufacturing departments.

The soft restrictions, which follow from the definition of the optimal combination, focus on a maximization of profit and a minimization of waste. The number of different orders in the combination is the profit, and the unused surface on the sheet and the amount of surplus products represent the waste. The last soft restriction relates to the planning; we put (unnecessary) time pressure on the manufacturing departments if we combine two orders with (very) different delivery dates.

2.2.5 Workforce planning

Once a week, on Thursday, the planning department makes a machine planning for the next week in an Excel spreadsheet; this machine planning states for every department, when production will takes place on which machines. All department managers must make sure that enough qualified personnel is present to operate the machines; to do this, they make a workforce planning. Planning uses the most recent workload planning of the upcoming week to make the machine planning. The department managers monitor the order intake daily, to adjust the workforce planning if required. Usually, Planning evaluates the workforce planning based on which machines are available per shift. This is especially relevant for the Finishing department, because of its diverse set of machines.

A workforce planning comprises of how many shifts they are going to work, who will work in each shift, which machines will be operated, and whether they are going to work overtime. As the departments Finishing and Hand Assembly have the possibility to hire temporary workers, this is also in their workforce planning.

2.2.6 Material planning

AVDS uses universal materials, as is typical to make-to-order companies (we discuss this later on). The main raw materials are carton sheets and trays (to hold data carriers). A supplier in China produces most of the carton and requires AVDS to place replenishment orders three months in advance. The supplier then ships the replenishment order to its local stock point in Enschede, where the carton stays until usage. The main sources, for determining the size of these replenishment orders, is historical data on the carton usage in previous years, and anticipated orders. AVDS uses a large safety stock level for the common trays, and places a purchase order when it requires unusual trays. Usually, Customer Service incorporates the lead time of this purchase order in the delivery period of the order. Customer Service has to define all required materials for every order. It bases the choice for a specific material on the actual stock of that material and the particulars of the order.

Warehousing & Shipping monitors the material requirements of the manufacturing departments daily. It determines which orders are due and releases and delivers the required materials to the various manufacturing departments. Upon a material release, the released amount of material of the entire order is automatically deducted from the stock level in the IS.

2.2.7 Shift planning and internal due dates

The planning department is responsible for planning all orders in the manufacturing departments. For every order, it sets the internal due dates for each production step in the routing. All manufacturing departments must finish an order before the internal due date of that order at that department (see Appendix C for an example of an order with internal due dates, within the IS). Planning uses time buckets of 8 hours (a shift), in which it assigns a set of orders (combinations in the case of Printing, Die Cut, and Separating) to every manufacturing department; in those 8 hours, the manufacturing departments must process, at least, that set of orders (see Appendix E for a typical list with the workload of a department).

2.2.8 Scheduling

As previously described, Planning prescribes every department which orders or combinations it should process in every shift. However, Planning does *not* dictate in which sequence the departments should process the orders or combinations; the manufacturing departments have the autonomy to determine the schedule themselves. The department employees have the technical expertise to decide on the best sequence of the orders or combinations in *their* department. For example, an optimal sequence in the Printing department may have the sheet size in decreasing order, the combinations with the same surface finish (coating) grouped, etc. Every department has its specific preferences concerning the sequence of the orders or combinations. The department employees have the autonomy to process the orders/combinations in the sequence that they perceive as optimal; that is, with minimal total lead time.

2.2.9 Shop floor control

The planning department plays a central role in coordinating the manufacturing processes; it keeps an eye on the progress in every manufacturing department. The planners do a lot of so-called firefighting activities (find solutions to (small) problems and disruptions). One of the three planners has a special focus on the Finishing department; he manually checks which orders the department currently works on, what the progress of an order is, and whether the required material is available. Warehouse & Shipping also tracks the progress of (critical) orders that are due for shipping that day. It contacts Planning and the various departments directly to urge them to finish the order in time or otherwise to be able to cancel agreements made with shipping agents (to prevent penalties). If an order requires processing by a third party (outsourcing), Planning communicates with these parties to ensure that they finish the order in time.

2.3 Key Performance Indicators at AVDS

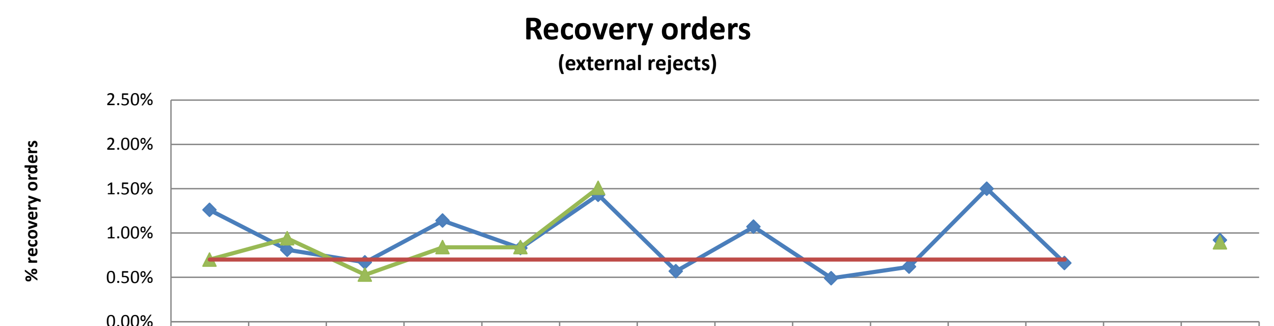
This section discusses the Key Performance Indicators (KPIs) that AVDS currently employs to monitor the performance of the organization and the manufacturing departments. AVDS uses KPIs on departmental level and organizational level. We focus only on the KPIs related to the manufacturing process and physical products/orders. Section 2.3.1 discusses the KPIs on the organizational level and Section 2.3.2 discusses the KPIs on the department level.

A KPI is a measure that focuses on those aspects of organizational performance that are the most critical for the current and future success of the organization (Parmenter, 2007), and conveys the most amount of information as possible in a single measurement (Peng, Sun, Rose, & Li, 2007). See Section 3.5 for a more thorough explanation of KPIs.

2.3.1 Organizational level

The KPIs, related to the manufacturing process and physical products/orders, on the organizational level are: number of recovery orders (external rejects), internal rejects, late deliveries, and external complaints.

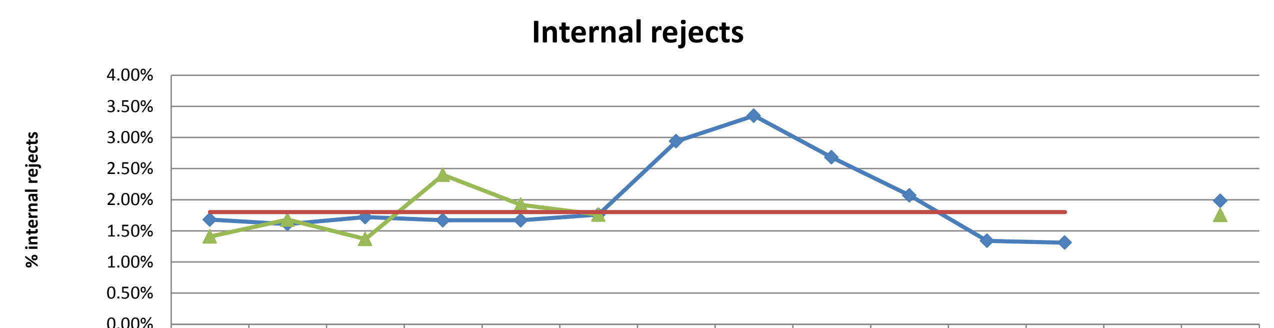
Every month, the department KAM communicates the performance of AVDS on each of these KPIs to the entire organization.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec		Avg
2011	1.26%	0.81%	0.67%	1.14%	0.83%	1.43%	0.57%	1.07%	0.49%	0.62%	1.50%	0.66%		0.92%
2012	0.70%	0.94%	0.53%	0.84%	0.84%	1.51%								0.89%
Target 2012	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%		0.70%

Figure 8: KPI recovery orders (from internal network).

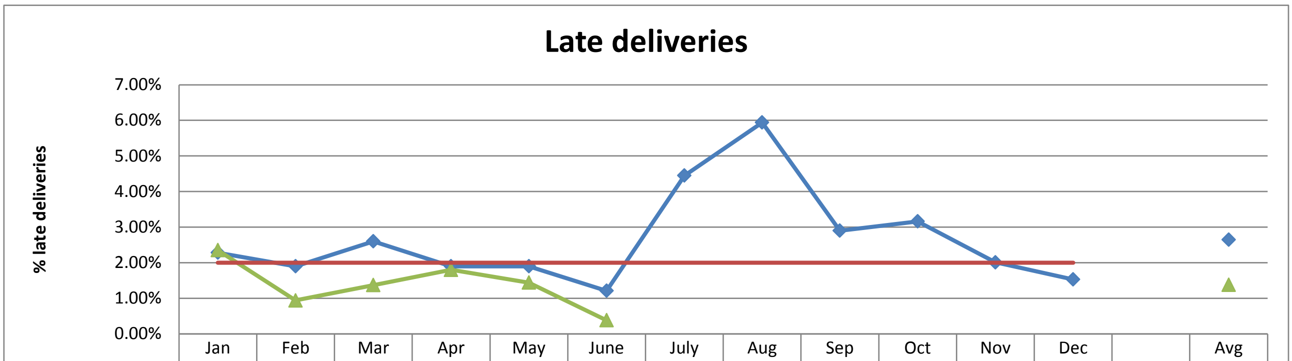
Figure 8 shows the number of recovery orders as a percentage of all orders. A recovery order is always linked to a regular order, but this regular order was not good enough according to the customer. So, AVDS produces the order again, or a part of it, to satisfy the needs of the customer. It is very important to have few recovery orders. AVDS aims to have, on average, a maximum percentage of recovery orders of 0.70%. We see that AVDS does not reach that objective.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec		Avg
2011	1.68%	1.61%	1.72%	1.67%	1.67%	1.76%	2.94%	3.35%	2.68%	2.07%	1.34%	1.31%		1.98%
2012	1.41%	1.68%	1.37%	2.40%	1.92%	1.76%								1.76%
Target 2012	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%		1.80%

Figure 9: KPI internal rejects (from internal network).

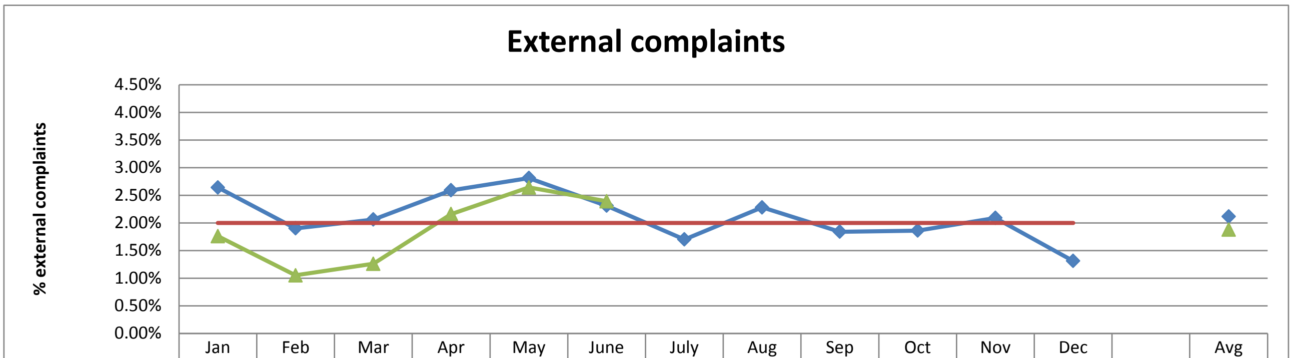
Figure 9 shows the number of internal rejects as a percentage of all orders. An internal reject may be caused by, for example, poor quality of the products in an order, and is identified before the order is shipped to the customer. Here, management aims to have a maximum of 1.80% internal rejects. We see that, on average, AVDS reaches that target, and that the percentage of internal rejects is higher in high season than in low season.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec		Avg
2011	2.28%	1.90%	2.60%	1.90%	1.90%	1.21%	4.45%	5.94%	2.90%	3.16%	2.01%	1.53%		2.65%
2012	2.35%	0.94%	1.37%	1.80%	1.44%	0.38%								1.38%
Target 2012	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%		2.00%

Figure 10: KPI late deliveries (from internal network).

Figure 10 shows the number of late deliveries as a percentage of all orders. This KPI is especially relevant for our research. The delivery reliability of AVDS relates closely to the late deliveries; that is, delivery reliability is 100% minus the percentage of late orders. The aim for this KPI is to have a maximum of 2% late deliveries, so AVDS strives for a delivery reliability of 98%. The peak we see in the data of 2011 is a yearly returning problem at AVDS; in July, many employees go on vacation, and directly after that, with the troubles of the vacation period still present, the high season starts in August, with the accompanying increase of new orders. The first part of 2012 is low season and we see that AVDS manages to, on average, reach its objective in this period.



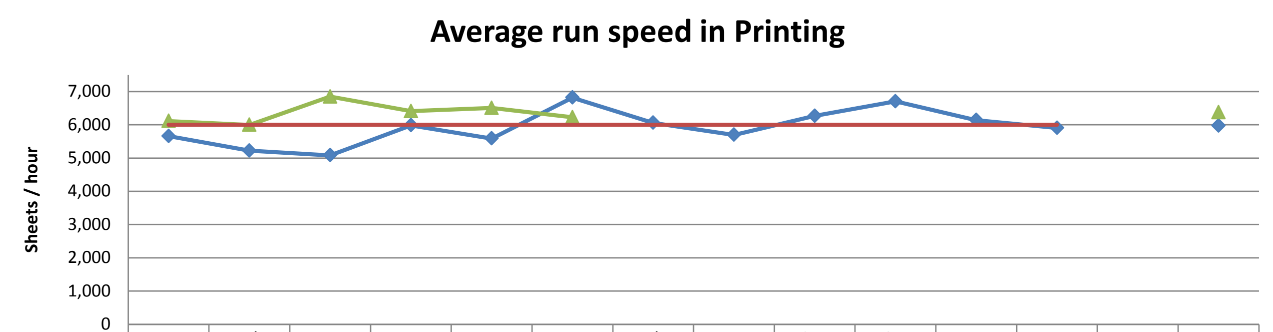
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec		Avg
2011	2.64%	1.90%	2.06%	2.59%	2.81%	2.31%	1.70%	2.28%	1.84%	1.86%	2.09%	1.31%		2.12%
2012	1.76%	1.05%	1.26%	2.16%	2.64%	2.39%								1.88%
Target 2012	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%		2.00%

Figure 11: KPI external complaints (from internal network).

Figure 11 shows the number of external complaints as a percentage of all orders. An external complaint is generated if a customer files a complaint about an order that was delivered to the customer. The aim is to have at the most 2% external complaints. On a yearly basis, AVDS almost reaches this objective, but per month, the maximum level of external complaints is frequently exceeded.

2.3.2 Departmental level

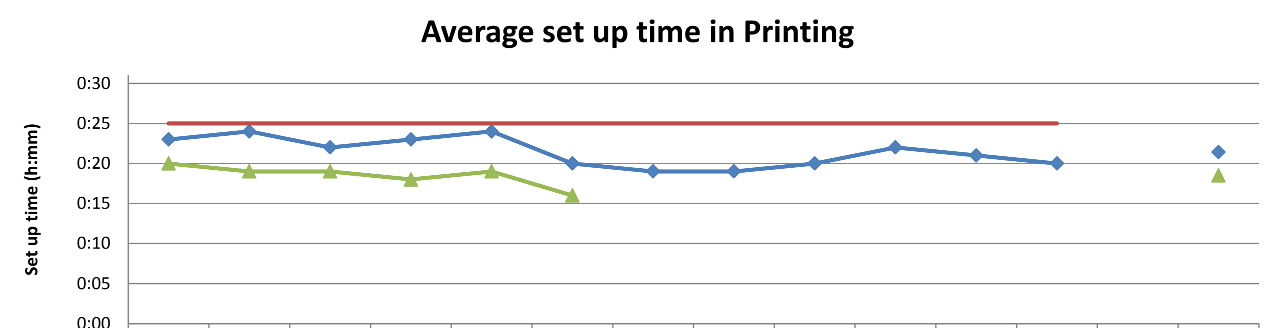
On departmental level, AVDS uses KPIs to monitor the performance of every department. The KPIs focus on the operational performance of the departments. Management of AVDS perceives that the average run speed and average set up time together, give insight in the operational performance of the manufacturing departments.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec		Avg
2011	5,657	5,222	5,082	5,984	5,588	6,816	6,057	5,695	6,265	6,702	6,139	5,905		5,973
2012	6,111	5,996	6,848	6,409	6,507	6,224								6,377
Target	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000		6,000

Figure 12: KPI average run speed, for Printing (from internal network).

Figure 12 shows the KPI average run speed. The values are for the Printing department. We see that Printing printed in 2011 on average 5,973 sheets per hour. The target for Printing is to print 6,000 sheets per hour, so, over 2011 Printing is just under the target, but from March 2012 to June 2012, Printing is above its target. Printing owes this to the fact that the average run length has increased (the printing presses require some startup time to run at full speed, which is roughly 9,000 sheets per hour). So, the longer the run length, the longer the press can run at full speed.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		Avg
2011	0:23	0:24	0:22	0:23	0:24	0:20	0:19	0:19	0:20	0:22	0:21	0:20		0:21
2012	0:20	0:19	0:19	0:18	0:19	0:16								0:18
Target	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25		0:25

Figure 13: KPI average set up time, for Printing (from internal network).

Figure 13 shows the KPI average set up time. This set up time is the time that Printing is occupied with setting up the printing presses for a specific order. If Printing must wash a press between two consecutive orders, this is not included in this KPI. Notice that this definition of set up time differs from our definition (see Section 1.6); we include cleaning time in the set up time. AVDS's aim is to have, an average set up time of at most 25 minutes, so with an average of 21 minutes in 2011 and 18 minutes in 2012, Printing stays well within the target.

Remember that, although Printing scores well in the KPIs on departmental level, our focus lies on the organizational level. Even if, for example, Printing would have perfect KPIs, but the delivery reliability is poor, then we still have a problem.

2.4 Analysis of shop floor data

This section analyzes shop floor data of the manufacturing departments. The shop floor data provides us with information on whether the departments performed as was planned, for all orders within a period. The period we analyze in this section, is the first quarter of 2012.

For every order that passes through the department, all departments (except Separating) have to register how long it works on the order (broken down into set up time and processing time). Computers in the departments, running an application in the IS, facilitate the registering process. In the past, management of AVDS decided that the Separating department does not have to register, because management perceived that the personnel in that department was unable to use such a 'complicated' application. The consequences of this decision are clearly visible in the shop floor data below, as follows from the result of the analysis.

Section 2.4.1 discusses what information the shop floor data contains and the measures we apply to remove data pollution. Section 2.4.2 presents the results of the analysis of the shop floor data. Section 2.4.3 concludes the analysis.

2.4.1 A closer look at the shop floor data

The shop floor data is collected in a spreadsheet, where each row relates to an order. Each column consists specific information about the order. For every order we have the following general information:

- order number,
- title,
- customer,
- product group,
- combination number, and
- shipping date.

Then, we have department-specific information for each of the manufacturing departments Printing, Die Cut, Separating, Finishing, Boxes, and Hand Assembly. The department-specific information consists the following for every order that passed through the department:

- planned and real set up time (the total set up time in this department on this order),
- planned and real processing time,
- planned and real time the order must be finished (that is, the internal due date and completion date),
- real start time of processing (currently, this is not planned, so only the real time is available), and
- planned and real number of products.

If the order was outsourced during the manufacturing process, then the data contains the time that the order was shipped to the third party (currently, this is not planned) and the time that the order returned (planned and real) to Warehouse & Shipping.

Cleaning the data

Strange numbers and irregularities are present in the data, consequences of, for example, mistakes in registering by the manufacturing departments. To cancel out some of the negative influences that these irregularities have on our analysis, we apply the following two rules (automated in a macro).

1. *When the real completion date of an order at a department is more than 7 days later than the planned completion date, then remove the real data of that department.*

If an order is more than 7 days late in a department, then we assume that something happened, such as:

- The order is on hold (in consultation with the customer) and the manufacturing process is paused until the order is released again. This means that the internal due dates are no longer valid.

- Very bad registration (or maybe the department even forgot to finish registration of the order).
- When an order has partial deliveries, then the start date may relate to the first part and the finish date may relate to the last part of the order.

2. *<u>When the real set up time is positive, but the real processing time is zero, then correct these times.</u>*

It may be that the machine operator forgot to set the registration from set up to processing; this means that the total lead time in that department is completely in the registered set up time. We correct the set up and processing times by using the fractions of planned set up time and planned processing time. So, we split the registered set up time of this order in the department, using the ratio between the planned set up time and planned processing time, as follows.

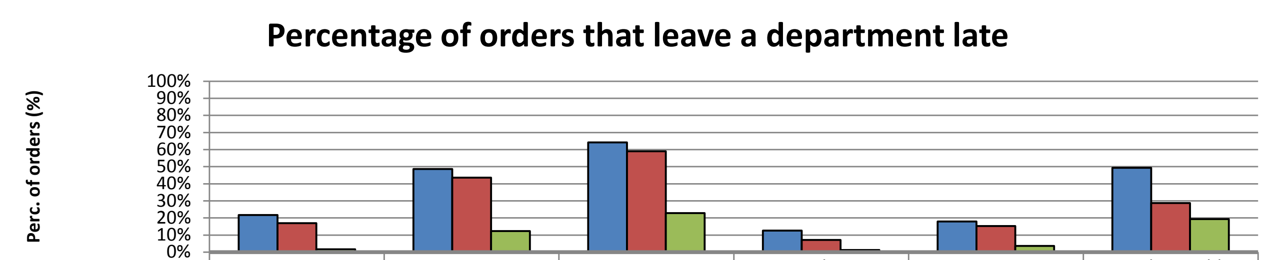
$$\text{fraction new real set up time} = \frac{\text{planned set up time}}{\text{planned set up time} + \text{planned processing time}}$$

$$\text{fraction new real processing time} = \frac{\text{planned processing time}}{\text{planned set up time} + \text{planned processing time}}$$

2.4.2 Analysis of shop floor data

We now have relevant information on how the manufacturing departments follow the planning. Figure 14 to Figure 20 visually depict the results from analyzing the shop floor data. Appendix G contains the complete set of tables and graphs of the analysis. After every figure, we discuss the things that stand out in it and suggest the causes. The next section, Section 2.4.3, draws conclusions from the analysis.

This analysis focuses on six manufacturing departments: Printing, Die Cut, Separating, Finishing, Boxes, and Hand Assembly. Boxes is a resource group of Finishing (see Figure 6), but because the characteristics of the orders Boxing are different from those in the rest of the Finishing department, we include it explicitly in this analysis. For example, the average set up time for an order in Boxes is roughly 2 hours, but in the rest of Finishing, this is roughly 30 minutes.



	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
% orders late	21.76%	48.67%	64.21%	12.67%	17.94%	49.33%
% orders >2h late	16.97%	43.62%	59.00%	7.13%	15.25%	28.67%
% orders >24h late	1.74%	12.27%	22.89%	1.26%	3.59%	19.33%

Department

Figure 14: Percentage of orders that leave a department late during Q1 of 2012.

Figure 14 shows the percentage of orders that leave a department late. It has three series, each shows how many orders – of all the orders in the analysis – were late in the first quarter of 2012. The first series shows what percentage of all orders is late; that is, all orders that have its real completion time later than its planned completion time (where the planned completion time is the internal due date). The second series shows what percentage of all orders is more than 2 hours late. And the third series shows what percentage of all orders is more than 24 hours late.

The first thing that stands out in Figure 14, is that every manufacturing department scores poorly in this figure. They breach the internal due dates of orders frequently and orders are often at least more than 2 hours late. We identify three causes, but the first is the most important. The *first* is that the culture at AVDS is to reduce set up times and increase run speeds, and that this is perceived to be more important than reaching the internal due dates. For example, see Figure 15 for a typical sequence of printed combinations in Printing. There, we see that 5 orders with a later internal due date were printed before the order with the internal due date of 1-2-2012, but that order is now more than 26 hours late. Right after this, we see the same thing happen again; this time the late order is more than 27 hours late. The reason for this odd sequence is probably that this sequence minimizes total set up time. So, culture overrules the internal due dates. The *second* cause is that MPC processes are fragmented, because the manufacturing employees make the schedule themselves (as described in Section 2.2). This leads to schedules that are good with respect to the total set up times at a specific department, but no optimization across different departments takes place. The *third* cause is that the KPIs that AVDS employs on departmental level, focus solely on the operational performance of the departments (see Section 2.3). For example, the KPIs in Printing are average run speed and average set up time. Obviously, these are not aimed at how the department performs with respect to the planning.

VO nr	CO nr	voltooid gepland	voltooid werkelijk	te laat?	afwijking tov planning
120066401	201200330	01-02-'12 06:00	31-01-'12 15:38	Op tijd	
120073001	201200359	01-02-'12 22:00	31-01-'12 17:33	Op tijd	
120074601	201200349	31-01-'12 22:00	31-01-'12 18:14	Op tijd	
120069801	201200343	01-02-'12 06:00	31-01-'12 21:33	Op tijd	
120067801	201200318	01-02-'12 14:00	01-02-'12 00:04	Op tijd	
120068201	201200317	30-01-'12 22:00	01-02-'12 00:21	Te laat	26:21
120067501	201200356	01-02-'12 06:00	01-02-'12 01:43	Op tijd	
120075901	201200378	01-02-'12 22:00	01-02-'12 07:43	Op tijd	
120079701	201200377	01-02-'12 22:00	01-02-'12 09:10	Op tijd	
120074801	201200355	31-01-'12 06:00	01-02-'12 09:11	Te laat	27:11

Figure 15: A typical sequence of orders in the Printing department.

Figure 15 shows a typical example of a set of combinations that are printed in the Printing department. In the sequence, we see that Printing cares little about the internal due dates of combinations.

Another thing that stands out from Figure 14 is that the percentage of late orders increases in the first three departments. In the first department (Printing), 22% of all orders is late, in the second (Die Cut), 49%, and in the third (Separating), 64% of all orders are late. We identify four causes. The *first* cause concerns the available capacity in Die Cut and Separating. This seems to be less than that of Printing and would result in breached internal due dates. The *second* cause is that the registration in Separating is poor. We previously explained that Separating is not required to register. In the data, we often see combinations that have a processing time that is either extremely short or extremely long (for example, several hours more than the expected processing time). Poor registration results in incorrect data, which pollutes the data, and makes us think that the percentage of late orders is (very) high. Although Separating registers extremely poor, the other department also make mistakes in registering. The *third* cause is that Planning always plans 1 hour for the lead time of a combination in Separating. The motivation for this is that (in theory) the Separating department can already start as soon as the Die Cut department finished one pallet of products, and that, in this manner, 1 hour is enough for most combinations. A consequence is that if a combination is more than one hour late in the Die Cut department, then the combination is also late in the Separating department. The *fourth* cause is that if the Printing department runs late, then the Die Cut department has smaller time windows for its combinations; Die Cut now has less freedom to optimize the sequence in which to manufacture the combinations. This results in more total set up time, because the sequence is less optimal. Now the Die Cut department is even less productive and runs even more late: a vicious circle. The same situation may occur between Die Cut and Separating.

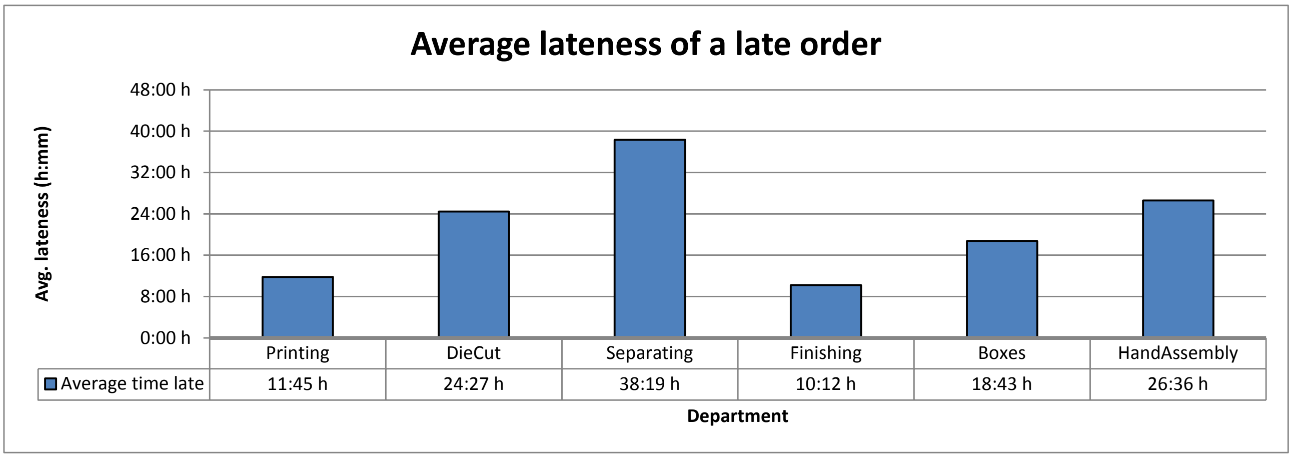


Figure 16: Average lateness of a late order during Q1 of 2012.

In Figure 16 we see the average lateness of a late order during the first quarter of 2012; orders that are on time are not included in this figure. The same pattern as in Figure 14 occurs in Printing, Die Cut, and Separating, again due to the causes that we discussed previously. The length of the average lateness however, is very long. This is caused by the culture that good operational performance is more important than following the planning, it causes the many breached internal due dates.

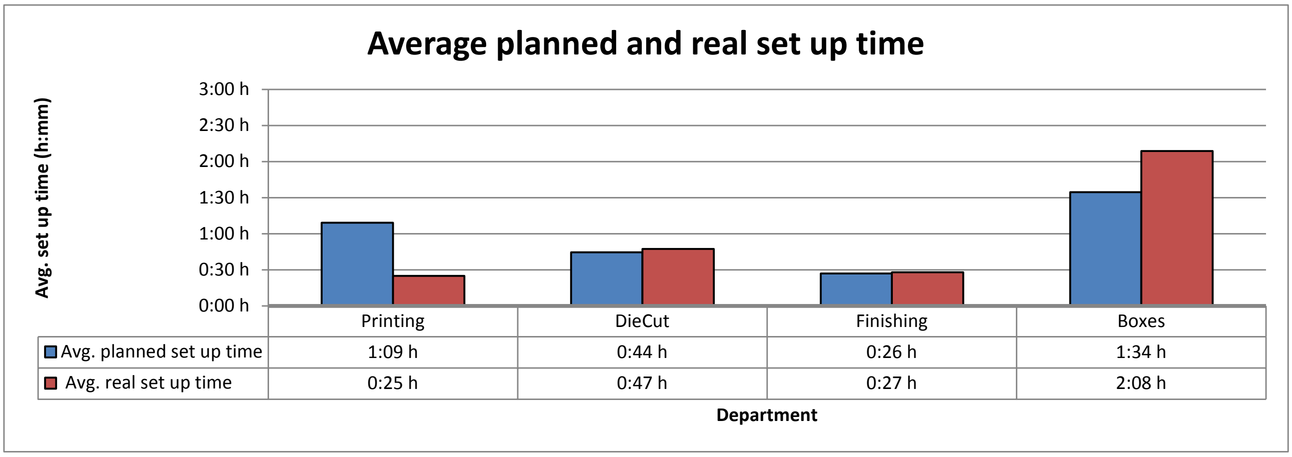


Figure 17: Average planned and real set up time during Q1 of 2012.

Figure 17 depicts the average planned and real set up time for Printing, Die Cut, Finishing, and Boxes. Separating and Hand Assembly have no (substantial) set up time, so we leave these out of the analysis.

What stands out in this figure, is that Printing has shorter set ups than planned. We identify two causes. The *first* cause is that the duration of a set up depends on the type of combinations involved, that is, set ups are long and highly sequence-dependent. Not all set ups take the same length of time, but the information system assumes they do. The *second* cause is that both the culture and the KPIs that AVDS employs on departmental level focus on minimizing the average set up time and maximizing the average run speed of the machines. So, it is very logical to expect that the average set up time decreases.

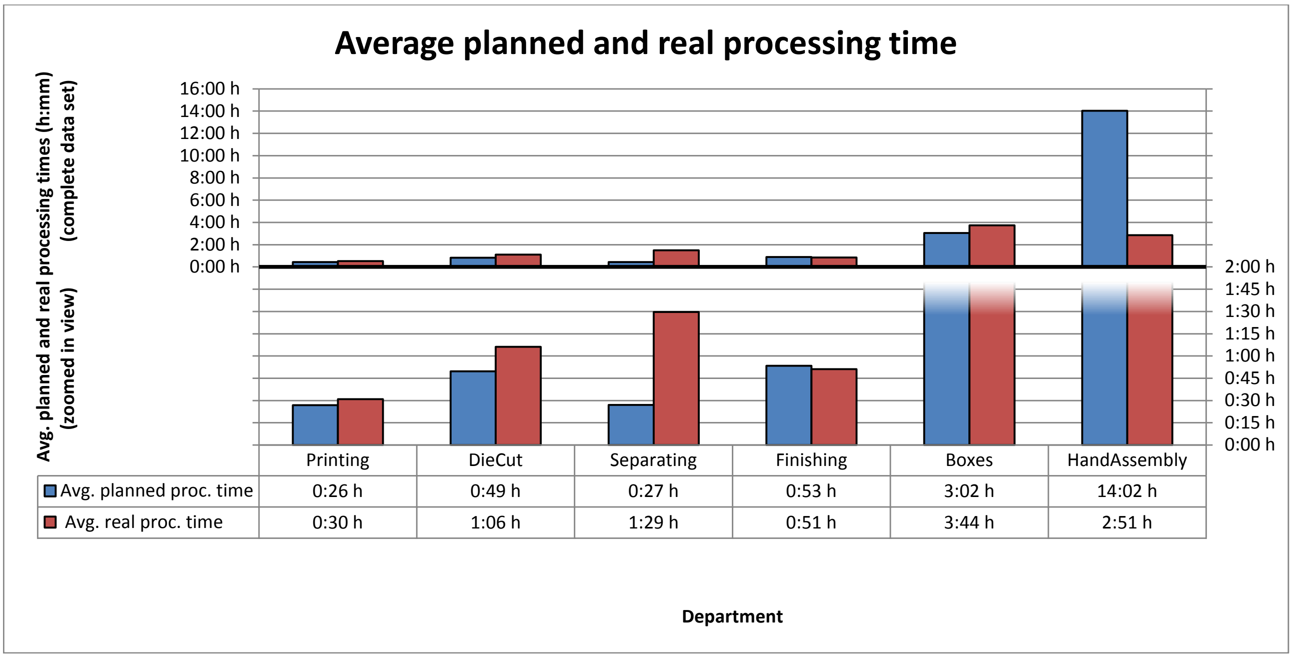


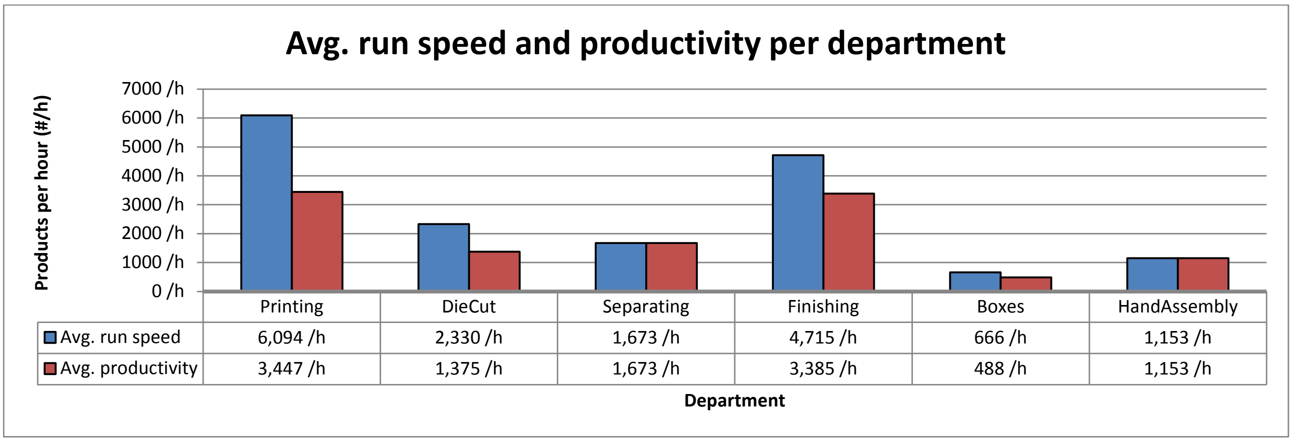
Figure 18: Average planned and real processing time during Q1 of 2012.

Figure 18 is very similar to Figure 17, with respect to the meaning of the values. The major difference is that we look at the average processing time instead of the average set up time. We also include Separating and Hand Assembly, because these do have processing times. Figure 18 consists of two panels, where the top panel shows the complete data set and the lower panel shows a zoomed in view, because of the large differences between the departments. The zoomed in view is restricted to 0 to 2 hours, where a gradient in the bar shows that the data continues outside this view.

One thing that stands out in Figure 18 is that Separating has longer processing times than planned. We observe two causes. The *first* is that Planning always plans 1 hour for the lead time in Separating. The *second* cause is that Separating registers very poorly, as we previously explained.

Another thing is that Hand Assembly has much shorter processing times than planned. This is caused by the simplistic estimation method of the required processing time at Hand Assembly. Hand Assembly works with temporary personnel. To estimate the expected processing time, Planning assumes a capacity of 4 employees to work on the order. However, while this assumption is valid in many cases, the actual capacity may be (much) higher, because Hand Assembly employs more temporary personnel if the workload is high. Then, the real processing time is (much) less than the expected processing time.

The last thing that stands out in Figure 18 is that Boxes has longer processing times than planned. This has two causes. The *first* is that Boxes sometimes has to wait for materials, because this department requires both paper and carton sheets; production cannot start until both are available, this results in more mistakes in the material supply. Because of the long average set up time (2 hours), Boxes cannot easily switch to another order, so, has to wait. The *second* cause is that, in determining the expected set up and processing times, the assumption is that Boxes has a run speed of 700 products per hour. We see in Figure 19 that this is higher than the real average run speed. This assumption may be unrealistic to achieve.



	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
Avg. run speed	6,094 /h	2,330 /h	1,673 /h	4,715 /h	666 /h	1,153 /h
Avg. productivity	3,447 /h	1,375 /h	1,673 /h	3,385 /h	488 /h	1,153 /h

Figure 19: Average run speed and productivity per department during Q1 of 2012.

Figure 19 gives an overview of the average run speed and productivity of the manufacturing departments. We define these terms as follows.

Run speed = *The number of products a resource actually produces per hour during processing. So, we focus solely on the processing time.*

Productivity = *The number of products a resource actually produces per hour during setting up and processing. This includes the set up time and processing time, but excludes waiting time; we focus on the lead time.*

We see that Separating and Hand Assembly have the same productivity as run speed, because they have no set up time. Also, we see that at Printing and Die Cut, roughly half of the average lead time is set up time and the other half is processing time; this emphasizes why these departments have such a strong focus on set up time reduction.

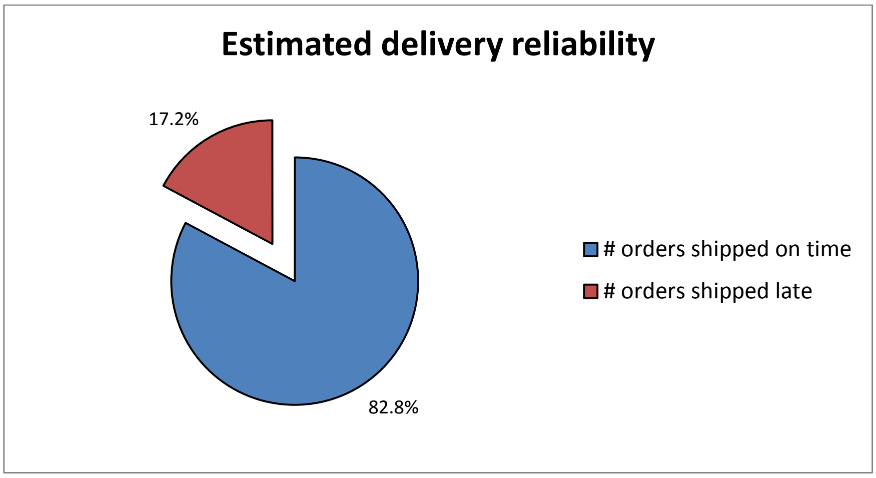


Figure 20: Estimated delivery reliability during Q1 of 2012.

Figure 20 shows the result of a rough estimation of delivery reliability. To calculate this, we determine for each order, when the last registration in the manufacturing department was and when the order should be delivered to the customer. Then we add 48 hours (the duration of regular transportation) to the time of the last registration. If the latter is later than the delivery date of the order, then the order is shipped late. In this way, we estimate what the delivery reliability would be if AVDS would not use expensive (but faster) transportation options. This is a quite rough method and has many disadvantages. However, it does provide us with insight into how much buffer AVDS has at the end of manufacturing processes.

The estimated delivery reliability is 82.8%. From the KPI late orders, which we presented in Section 2.3, follows that delivery reliability in Q1 of 2012 was (100% - % late orders) 98.45% (the average of January, February, and March). The difference between our estimation and the reported delivery reliability has three causes. The *first* cause is that AVDS uses faster transportation means to get an order that runs late, still in time at the customer. AVDS spent in 2011 more than €70,000 and in Q1 of 2012 more than €7,500 on faster transportation means, to get late orders to the customer in time; faster also means more expensive transportation; keep in mind that it was low season in Q1 of 2012. The *second* cause of the difference is that our calculation method to estimate the delivery reliability selects the earliest delivery date of the order and the last registration of that order in the manufacturing departments. If an order consists of several partial deliveries, then our equation selects the shipping date of the first part and the last registration of the last part in the order. So, the order may be marked as late because, for example, the last part was processed later than the first part's delivery date. This is a flaw in the calculation method, but inherent to AVDS's order structure; we discuss this in more detail later on. The *third* cause is AVDS's definition of a late order. Currently, if an order runs late, Customer Service contacts the customer and asks if the order may be delivered later; if the customer agrees, then the delivery date is updated in the IS. If the order arrives at the customer in time according this new delivery date, then the KPI registers the order to be on time. However, the customer obviously perceives the order as late. If the customer does not agree with Customer Service's request, then the KPI registers the order as late.

2.4.3 Concluding the analysis

In the above analysis, we identify and explain several major issues that cause negative results in our analysis. Here, we conclude the analysis. Table 2 gives an overview of all causes and the impact – as we perceive – each cause has on the performance of AVDS's manufacturing system in the shop floor data analysis.

Cause	Low impact	Medium impact	High impact
1. The culture is that operational performance is more important than planning			X
2. MPC processes are fragmented		X	
3. KPIs focus on operational performance		X	
4. Capacity in Die Cut and Separating may be insufficient			X
5. Separation performs no / poor registration		X	
6. Planning plans lead time of 1 hour in Separating	X		
7. If Printing is late, then Die Cut has smaller time windows	X		
8. Set up times are long and highly sequence-dependent			X
9. Simplistic estimation method of required processing time in Hand Assembly	X		
10. Boxes sometimes has to wait for materials		X	
11. Estimation method of required processing time in Boxes assumes (too) high run speed	X		
12. Partial deliveries pollute shop floor data		X	
13. Definition of late orders is debatable	X		

Table 2: Overview of all causes of negative results in the shop floor data analysis.

In Table 2, we denote for every cause, which we identified in the shop floor data analysis as discussed in the previous section, the impact that we think that the cause has on the performance of AVDS's manufacturing system. We distinguish three levels of impact, low, medium, and high impact. A cause has a high impact if it costs AVDS serious money, in the form of lost sales or expenditures. A cause with medium impact hinders the manufacturing system, but matters little in terms of serious money. A low impact cause is a minor issue. We discuss the causes with a high impact below.

We have three causes with a high impact on the performance of AVDS's manufacturing system: (1) the culture is that operational performance is more important than planning, (2) capacity in Die Cut and Separating may be insufficient, and (3) set up times are long and highly sequence-dependent. The first cause focuses on the culture, we already mentioned this problem frequently in this thesis. The second cause concerns the available capacity in Die Cut and Separating; however, this is not directly related to the MPC processes and, as such, is out of the scope of this thesis. The last cause is that set up times are long and highly sequence-dependent, but however complicating this may be for AVDS, it is a distinct characteristic of AVDS's manufacturing system and the type of products AVDS makes.

So, of the three causes that have a high impact, we focus solely on the first: the culture in AVDS's manufacturing systems. To change this culture, we will have to radically change the principles of the MPC processes. We will have to make sure that planning is leading again. When people make an agreement on the course of action, they must stick to their word; obviously, this should also be valid in planning manufacturing departments. We identify the following two important principles that our redesign should reflect.

> *1. Planning is leading*
>
> *2. We freeze the planning beforehand*

3. Literature

So far, we analyzed AVDS, its MPC processes, and the performance of its manufacturing processes in Chapter 2. We now need to acquire relevant literature that can help us construct a redesign of AVDS's MPC processes, to change the culture and solve the problem that AVDS's MPC processes are fragmented. In this chapter, we review such relevant literature. Section 3.1 discusses a manufacturing system typology, Section 3.2 discusses several order types, Section 3.3 discusses and reviews various MPC frameworks and constructs a suitable framework, Section 3.4 discusses scheduling aspects, Section 3.5 focuses on Key Performance Indicators, and Section 3.6 suggests an implementation roadmap.

3.1 Classifying AVDS's manufacturing system

We first have to know what manufacturing system typologies exist, and which applies to AVDS. This is important in order to be able to apply the right theory. Zijm (2000) proposes such a typology to classify manufacturing systems; he distinguishes two dimensions and an orientation. The dimensions are 'logistic product/market relation' and 'internal organization'. The orientation is either a capacity or material orientation. Sections 3.1.1 to 3.1.3 discuss the three classification criteria and determine which one applies to AVDS's manufacturing system.

3.1.1 Logistic product/market relation

Zijm (2000) discusses four different structures of the logistic product/market relation: Make and Assemble to Stock (MATS), Make to Stock and Assemble to Order (MTS/ATO), Make to Order (MTO), and Engineer to Order (ETO).

With *MATS*, the manufacturing system produces (make and assemble) to stock, and performs order fulfillment by delivering from stock. This is the typical production philosophy for the majority of consumer products, such as electronic equipment, food, and drugs. With *MTS/ATO*, the system produces a large variety of products, but from a limited number of components. It makes sense to produce the components to stock (MTS), but perform the final assembly based on a customer order (ATO). Car manufacturing is a good example of MTS/ATO. With *MTO*, a system faces a large variety of products in small quantities; the variety originates already at the component level. A high degree of customization of the products is possible. In principle, materials are universal and often procured based on forecasts. With *ETO*, manufacturing systems typically design and engineer products based on a functional description of the customer, and in close cooperation with the latter. Only after reaching agreement on the product design with the customer, the system initiates (physical) manufacturing.

The main distinction between the above structures is how a manufacturing system serves its customers and how it fulfills its orders. Usually, the selection of a particular structure is a trade-off between a short delivery period on the one hand and small stocks of finished goods on the other hand. MATS usually has a short delivery period and high stocks of finished goods; ETO usually has long delivery periods and no stocks of finished goods. Key parameters in the trade-off are product life cycle (the 'life' of a product from its introduction to its discontinuation), the diversity of the product range, the degree of customization of end-items, and processing times (Zijm, 2000).

AVDS serves its customers using a mix between MTO and ETO. The majority of the products in the media category are MTO; a wide variety exists, but most products fall within distinct product families. AVDS does not produce any products to stock. AVDS customizes every order to the wishes of the customer. With the non-media category, we see a completely different situation; AVDS actively develops new non-media products from scratch and often in close cooperation with a customer. We can best classify this way of working as ETO.

3.1.2 Internal organization

The internal organization dimension describes the internal structure of a manufacturing system. This structure may differ per department. Zijm (2000) identifies 3 basic structures (1) dedicated (mixed model) flow lines, (2) job shops, and (3) on-site manufacturing. The dedicated (mixed model) flow line structure is widely known as the flow shop structure.

Flow shops have high volumes and limited product variety. A classic example of this structure is an assembly line designed for a specific product (or product family). Also, manufacturing systems in which products follow more or less the same routing can be set up as flow shops. *Job shops* produce a wide variety of products, usually in low volumes. Job shops often have a functional layout. *On-site manufacturing* has one main characterization, all required equipment is transported to the product's site; for example, the realization of complex infrastructural works such as bridges or tunnels (Zijm, 2000). Pinedo (2009) emphasizes that the flow shop structure is a special case of the job shop, where each one of the jobs has to follow the same route through the system.

These three structures represent the extremes of an almost continuous spectrum of hybrid structures. The trade-off in selecting a structure is usually between efficiency and production speed (Zijm, 2000).

Elmaghraby and Karnoub (1997) define a specific case of a hybrid structure, that of the *hybrid flow shop*. A hybrid flow shop consists of series of production stages, each of which has several machines operating in parallel. Some stages may have only one machine, but at least one stage must have multiple machines. The flow of jobs through the shop is unidirectional (in one direction only). Each job is processed by one machine in each stage and it must go through one or more stages. Machines in each stage can be identical, uniform or unrelated. Further characteristics (Ruiz & Vázquez-Rodríguez, 2010) are the number of production stages is at least 2, and a job might skip any number of stages provided it is processed in at least one of them.

AVDS's internal structure is a hybrid flow shop; when we look at Figure 6 (in Chapter 2), this becomes clear, because the various manufacturing departments have one or more machines. Also, as most orders follow the routing (shown in Figure 7 in Chapter 2), the flow of jobs through the shop is unidirectional.

3.1.3 Orientation of the system

The last dimension we use to distinguish manufacturing systems, is the orientation of the manufacturing system. In other words, is a system materials-oriented or capacity-oriented?

Manufacturing systems involved in high volume assembly of products that consist of purchased components, usually add little value to the product. These companies therefore have a strong focus on the materials it uses; it is materials-oriented. Capacity-oriented manufacturing systems use a limited variety of basic materials and produce a wide variety of products; they usually add substantial value to the product. Capital-intensive equipment may be required. The focus of such a manufacturing system is mainly on its resources and capacity.

AVDS uses very universal materials (carton and trays) and has a large variety of products. So, the orientation of AVDS's manufacturing system is therefore capacity-oriented.

3.2 Order structure

Now we know how to classify AVDS's manufacturing system, we focus on the order structure. The order structure describes how various types of orders (such as, customer orders) relate to each other. We saw in

Chapter 2 that the current order structure at AVDS has several disadvantages, such as, if an order consists of several partial deliveries with different due dates, the available shop floor data gets mixed up severely. This section discusses a new type of order from literature, which may be a useful addition on the current order structure at AVDS. Chapter 4 discusses how the new order type may be integrated in the current order structure.

Many authors make a distinction between customer orders and jobs, where a *customer order* is placed by a customer and contains information on the specific product(s) that the customer requests. A *job* is the restriction of a customer order to the manufacturing system's resource groups (Zijm, 2000) (a customer order concerns every department in the entire organization, but a job only concerns the manufacturing departments). A job also, according to Hopp and Spearman (2008), refers to a set of physical materials that traverses a routing, along with the associated logical information. Pinedo (2009) states that a job typically consists of a number of operations that have to be performed in different resource groups, and that each job has its own routing through the manufacturing system. Every job is triggered by either an actual customer order or the anticipation of a customer order (Hopp & Spearman, 2008), and is directly derived from this customer order (Zijm, 2000). Figure 21 shows the direct relation between customer orders and jobs, this is the order structure; each customer order consists of at least one job, but more jobs may be necessary if, say, the customer order needs to be processed and shipped in several partial deliveries.

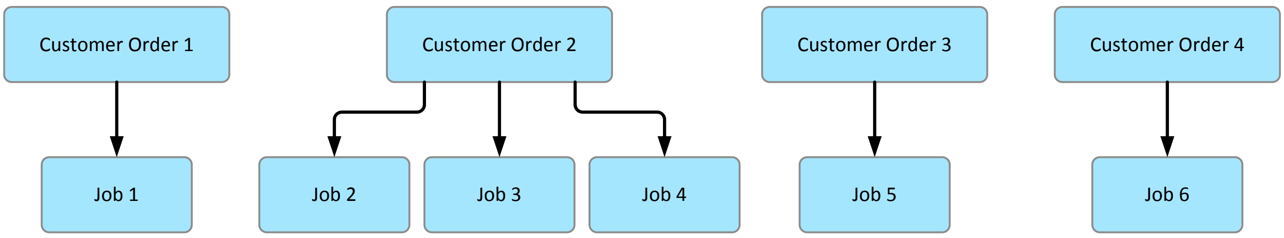


Figure 21: An order structure: the relation between customer orders and jobs.

We now know what a customer order is and what a job is, and the relation between the two. We discuss the properties of customer orders and jobs in somewhat more detail. The list below gives an overview of the properties that the job should have, based on Pinedo (2009), and gives per property a brief explanation.

- *Number of products*, the number of products to manufacture;
- *Internal release date*, the time the job arrives at the system: the earliest time its processing can start;
- *External release date*, the time at which the customer order is placed;
- *External due date*, the delivery date as promised to the customer;
- *Routing with the expected lead times*, the routing of the job with the expected set up and processing time that the job has to spend in every resource group in the routing;
- *Internal due dates*, the planned times at which the job must be completed in every resource group in the routing.
- *Start dates*, the expected times at which the job starts its processing in every resource group in the routing, as determined by the schedule;
- *Completion dates*, the expected times at which the job is completed in every resource group in the routing, as determined by the schedule.

In Chapter 4, we use the above discussion on order structure, to construct and propose a new order structure at AVDS, where we integrate the job into the order structure. The principle that forms the basis of this redesign is that 'jobs are the operational entities to be controlled at the shop floor' (Zijm, 2000); for AVDS this means that jobs will replace the position of the customer order in the manufacturing departments. As said, we continue this discussion in Chapter 4.

3.3 Selection of an MPC framework

This section aims to find an appropriate MPC framework. In a framework, we view the different aspects of MPC and map the relations between these aspects (Vollmann, Berry, Whybark, & Jacobs, 1997). We describe the MPC processes as a system, composed of various modules; a module focuses on one specific aspect related to MPC. We start in Section 3.3.1 with constructing a four-by-three matrix, with which we decompose the MPC processes; then, in Section 3.3.2, we compare several MPC frameworks; finally, we adapt in Section 0 the framework of Zijm (2000) to create a fit with AVDS.

3.3.1 Decomposing the MPC processes

We describe how we decompose the MPC processes into two dimensions. Zijm (2000) proposes to decompose the MPC processes into the following two dimensions: (1) hierarchical decomposition and (2) decomposition with the subject area of the MPC modules, as shown in Figure 22.

Most MPC approaches use some sort of hierarchical decomposition. The fundamental work of Anthony (1965) already used three levels of managerial decision making. Fleischmann and Meyr (2003) pose that it is not possible to tackle all planning tasks with one comprehensive, overall planning model simultaneously. Moreover, they state that it would not even be useful, because of four reasons: (1) the amount of uncertainty increases with the length of the planning horizon, (2) different planning horizons imply different planning frequencies, (3) planning tasks on different planning horizons need a different degree of aggregation (in terms of time, place, products, and resources), and (4) decisions with varying importance involve decision-makers with varying responsibilities and influence. These reasons imply that we need 'planning modules' that pool all decisions that require similar responsibilities, share a similar planning horizon, and have strong interdependence (Fleischmann & Meyr, 2003).

The first dimension is *hierarchical decomposition*. Zijm (2000) distinguishes three levels in hierarchy: the strategic, tactical, and operational level. *Strategic planning* addresses decisions that affect the entire manufacturing system, considering a long planning horizon of multiple years; these decisions essentially determine the structure of the organization and should directly reflect a organization's business strategies. *Tactical planning* uses and acts within the infrastructure set by the strategic planning, and usually on an intermediate planning horizon of weeks to months. *Operational planning* puts the guidelines, set by tactical and strategic planning, into practice (Fleischmann & Meyr, 2003). Hans, van Houdenhoven, and Hulshof (2011) split the operational level into an *offline* and *online operational* level, where the first makes short-term decisions in advance and the second monitors and controls the manufacturing processes in real-time.

The second dimension is *decomposition with subject of the MPC modules*. Zijm (2000) distinguishes three subjects: technological planning, resource capacity planning, and material coordination. Technological planning is about the development of (new) products and the design of the manufacturing process. Resource capacity planning employs all resources in the manufacturing system (such as machines). Material coordination controls stocks, raw materials, and finished products (Zijm, 2000).

	Technological Planning	Resource Capacity Planning	Material Coordination
Strategic			
Tactical			
Offline Operational			
Online Operational			

Figure 22: Matrix for decomposition of MPC processes (Hans et al., 2011; Zijm, 2000)

Figure 22 shows the four-by-three matrix, with the two dimensions as discussed above. We see in vertical direction, the hierarchical levels: the strategic, tactical, offline operational, and online operational level. The higher in the matrix, the higher the level of aggregation and uncertainty is. The horizontal direction depicts the decomposition by subject area, which are technological planning, resource capacity planning, and material coordination. We can place any module in this matrix, for example, shop floor control, which monitors and controls the actual progress in the manufacturing system; we place this in the 'online operational' row (as it monitors and control the manufacturing system in real-time) and the 'resource capacity planning' column (resources are utilized to make progress).

3.3.2 Overview of MPC frameworks

In this section, we briefly discuss and compare various Manufacturing Planning and Control frameworks from literature.

In the last decades, many new approaches have been developed in the research area of MPC. Most frameworks have some kind of hierarchical decomposition, often decomposed, as Zijm (2000) discusses, into a strategic, tactical, and operational level. However, Hans et al. (2011) explain that the classical MPC frameworks have a specific orientation on either technological planning, resource capacity planning, or material planning; Zijm (2000) argues that this focus on one managerial area is the main cause that these MPC frameworks are inadequate in practice. Therefore, we construct a framework in Section 0 that integrates the different managerial areas. But first, we give an overview of several existing frameworks.

Hopp and Spearman (2008) propose an MPC framework based on the CONWIP principle (from CONstant Work In Progress), the key aspect of this framework follows from its name; it strives to have a constant amount of work in progress (WIP) in the manufacturing system, where WIP includes all unfinished parts or products that have been released to the manufacturing system (Hopp & Spearman, 2008). The focus of their framework is solely on resource capacity planning. It disregards explicit modules in material coordination and addresses technological planning only briefly.

Vollmann et al. (1997) present a framework that includes, in addition to the resource capacity planning area, some issues in the material coordination area into account. This framework employs a hierarchical decomposition and integrates demand management, capacity planning and material requirements. The engine of the framework, however, is based on material requirements planning (better known as MRP), which has several significant shortcomings; three of the most severe are (1) capacity infeasibility of MRP schedules, (2) long lead times, and (3) system nervousness (Hopp & Spearman, 2008). For comprehensive discussions on MRP, see Hopp and Spearman (2008), Orlicky (1975), Silver, Pyke, and Peterson (1998), Stevenson, Hendry, and Kingsman (2005), or Vollmann et al. (1997).

Zijm (2000) develops a framework that does incorporate all three managerial areas (technological planning, resource capacity planning, and material planning). He focuses especially on integrating material coordination and capacity planning, in contrast with most MRP-based approaches, and on integrating technological planning and resource capacity planning. This framework is developed for both Make to Stock (MTS) and Make to Order (MTO) manufacturing system, AVDS employs the latter.

Many more MPC frameworks have been developed in the last decades; see for a review of existing MPC frameworks, for example, Stevenson et al. (2005), Zäpfel and Missbauer (1993), or Zijm (2000). As Zijm (2000) focuses strongly on the integration of all three managerial areas and targets on MTO manufacturing systems, the framework of Zijm (2000) will form a solid basis of our redesign.

3.3.3 Adapting the MPC framework

In this section, we adapt the framework that Zijm (2000) proposes to make a fit with AVDS. The strategic level in the framework is out of scope, because this deals with long-term decisions and is highly intertwined with AVDS's current business strategies, on which we have no influence. So, we focus on the tactical and operational level.

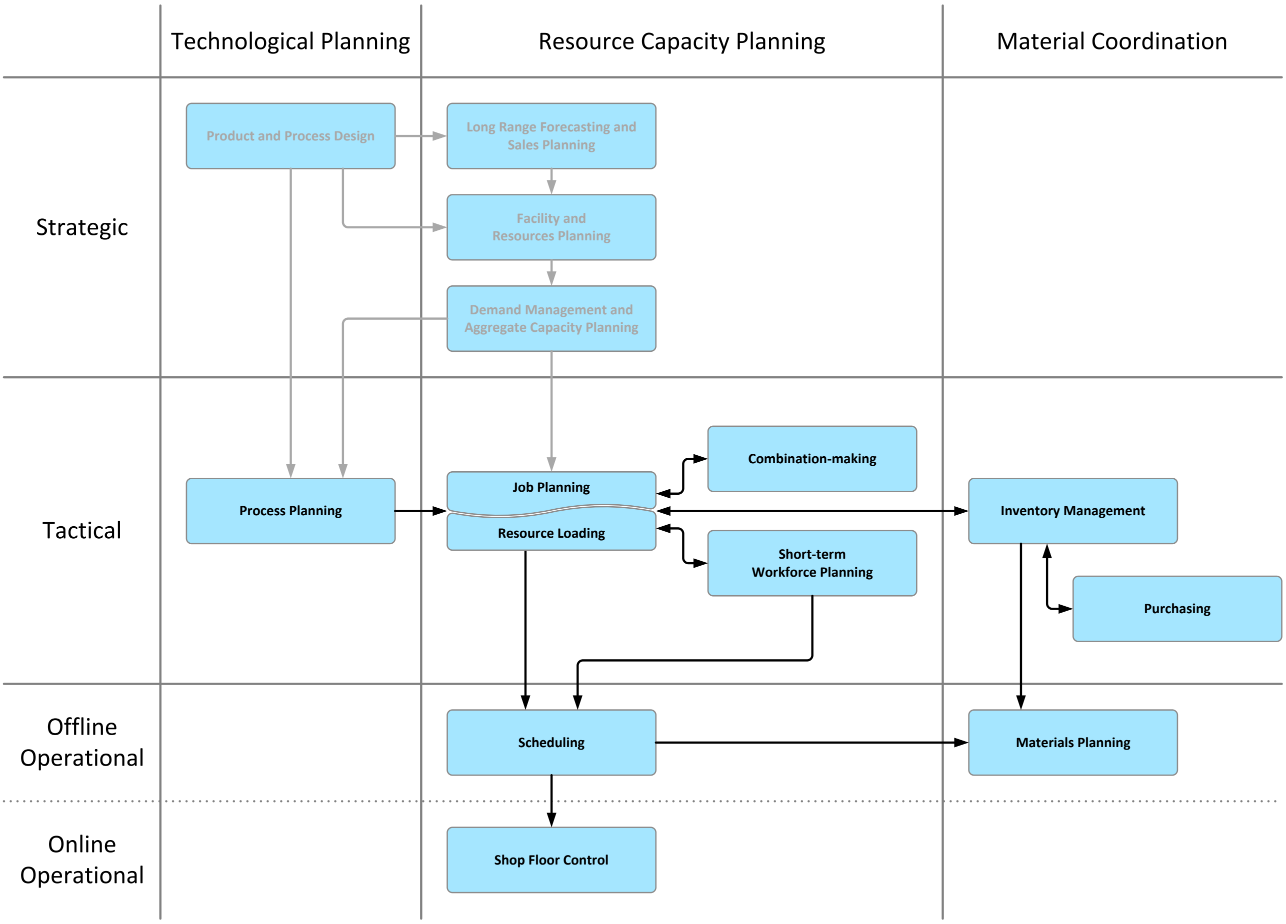


Figure 23: MPC framework adapted for AVDS.

Figure 23 shows an adapted version of the framework of Zijm (2000); we adapt it to make a fit with AVDS. The positioning matrix from Section 3.3.1 is the basis, in which we position each module of the framework. The rows in Figure 23 depict the three hierarchical levels: strategic, tactical, and operational (offline and online). The columns depict the three managerial areas: technological planning, resource capacity planning, and material coordination. The arrows depict the flow of information between the modules. We explain the individual modules in the framework in the remainder of this section.

Process planning

Usually, there is a distinction between macro and micro process planning. Macro process planning concerns the selection of routings and the global estimation of processing times (Zijm, 2000). Micro process planning concerns a more detailed level, but this is not relevant in the case of AVDS. Process planning provides input to job planning and resource loading.

Job planning and resource loading

Job planning and resource loading could be seen as two different modules, but they interact so intensively, such that we depict and handle them as one module. Once customer orders are accepted and macro process plans are made, jobs can be constructed (Zijm, 2000). Recall from Section 3.2 that a job basically consists of a number of operations that have to be performed in different resource groups, and that each job has its own routing through the manufacturing system (Pinedo, 2009).

This module concerns two different aspects. *Job planning* assigns jobs to specific resources (depending on the routing) in a shift; it determines the internal release and due dates for every job at every resource group. Once the jobs are constructed, *resource loading* loads jobs to resource groups. Resource loading aims at matching the required and available capacity within each resource group, by simultaneously loading the groups. It considers effective resource group capacities as well as routing constraints of jobs between the resource groups, but not within the resource groups (Zijm, 2000).

A complicating factor however, is AVDS's use of combinations. As said, the departments Digital Services, Printing, Die Cut, and Separating work with combinations, which are actually sets of one or more jobs. This means that job planning and resource loading interacts often with the combination-making module, because the aforementioned departments cannot be loaded until the jobs are combined.

If a job is not combined yet, the expected processing time is still unknown in Digital Services, Printing, Die Cut, and Separating. This means that we cannot determine the exact internal release and due dates in these departments. We can load the other manufacturing departments (such as Finishing), but we must wait loading the jobs to Digital Services, Printing, Die Cut, and Separating until the jobs are combined. This means that the planning horizon for these departments, which work with combinations, is significantly *shorter* than in the other manufacturing departments.

We see this very strong interaction between and interdependency of job planning and resource loading and combination-making also depicted in Figure 23. Job planning and resource loading also has a close relation with inventory management (a job can only be loaded in a specific shift is the required material is available at that time) and short-term workforce planning (sufficient personnel must be present in every shift to operate the loaded machines). Job planning and resource loading provides input to the scheduling module.

Combination-making

In combination-making, Planning combines jobs into combinations. The manufacturing departments Digital Services, Printing, Die Cut, and Separating work with combinations, instead of jobs. Section 2.2.4

discussed combinations extensively. The combination-making module is case-specific to AVDS and as such, Zijm (2000) does not have it in his framework. Combination-making closely interacts with job planning and resource loading.

Short-term workforce planning

Short-term workforce planning is a module that Zijm (2000) does not have in his framework. It plans personnel in each resource group on a short-term (on a weekly basis). The long-term workforce planning falls under the facility and resources planning module, in the strategic level. If resource loading assigns jobs to a resource group, then sufficient personnel must be available for this resource group. Mainly because of this dependency (resource loading cannot load a resource group if workforce planning has no personnel available), workforce planning has a close relation with job planning and resource loading. The workforce plan serves as input to the scheduling module.

Inventory management

Inventory management monitors the stocks in the warehouses of AVDS (this excludes WIP in the manufacturing departments) (Zijm, 2000). When a job is constructed at job planning and resource loading, inventory management reserves the required materials and generates a purchase order, if needed. Inventory management prescribes materials planning which material movements to execute. Inventory management and purchasing cooperate to make sure that all the required materials are available at the time they are needed.

Purchasing

Purchasing takes care of all the purchases from external suppliers. Typically, this comprises of acquiring material that is not in stock or new tooling, which is required for a job (Zijm, 2000). Purchasing has a close relation with inventory management.

Scheduling

Scheduling sequences individual jobs on all machines in every resource group (Zijm, 2000). The goal is to meet the internal due dates of the jobs, set at job planning and resource loading. A schedule provides the sequence in which jobs are to be done and projects the start time of each job at each resource (Silver et al., 1998). Job planning and resource loading provides the required input to scheduling. The resulting schedule serves as input to materials planning, as the schedule prescribes which materials are needed when and where.

Materials planning

We define Materials planning as a separate module, where Zijm (2000) handles it in combination with inventory management. Inventory management deals with decisions on the tactical level, where materials planning acts within the operational level; it is more intuitive to handle these as two distinct modules. Materials planning is responsible for providing all resource groups with the required materials. Inventory management informs materials planning which movements and replenishments must be made, and scheduling informs materials planning when these movements and replenishments must be done.

Shop floor control

Shop floor control monitors and diagnoses all activities of all resource groups, reports on quality aspects, and signals and responds to disruptions in the manufacturing process (Zijm, 2000). The schedule contains the information that shop floor control needs, to control the resource groups.

3.4 Scheduling

The scheduling module focuses on sequencing jobs on resources within the restrictions determined by resource loading. That is, basically, resource loading determines in which period a job must be processed, and scheduling determines the sequence of the jobs within the period. This section focuses on the scheduling module from the adapted MPC framework from Section 0.

In literature, Silver et al. (1998) suggest to make schedules on a rolling horizon basis, but only the first period of the schedule is implemented. Then, at the end of the first period, a new rolling horizon is used to establish a new schedule (Silver et al., 1998). So, we look multiple periods ahead, but execute only the schedule of the first period, and make a new schedule for the second period as we arrive at the second period.

Silver et al. (1998) also suggest that the schedule of the first period is determined *before* the start of the period, for the complete period. So, *freeze* the schedule before it is executed.

3.5 Key Performance Indicators

Using Key Performance Indicators (KPIs) is critical for monitoring the performance of a manufacturing system accurately. It helps an organization to communicate its strategy to employees and gives insight in how much employees comply to objectives. Using KPIs leads to process improvements and improved organizational effectiveness (Ganesan & Paturi, 2009). This section discusses what a KPI is and how an organization may use it.

If a manufacturing process has a certain performance, then we can measure this using a *performance indicator*. A performance indicator is a quantitative and periodic measurement of one or more processes (Peng et al., 2007). A *key performance indicator* (KPI) is a measure that focuses on those aspects of organizational performance that are the most critical for the current and future success of the organization (Parmenter, 2007), and conveys the most amount of information as possible of the performance (Peng et al., 2007).

So, a KPI reflects the organization's vision and strategy, is easy to interpret and actionable, decided by management, and tied to roles, processes, system capabilities, and products/services of the organization (Ganesan & Paturi, 2009).

A good example of a KPI is the percentage of late deliveries during a specific period, which AVDS uses to monitor the delivery reliability of the organization. It reflects that AVDS's management envisions that AVDS should be an organization that its customers can rely on.

KPIs can convey the health of (a department of) an organization (Peng et al., 2007) and quantify and visualize the performance of the organization. So, AVDS can use KPIs to monitor the performance of the separate (manufacturing) departments and of the entire organization. This enable management of AVDS to proactively steer the organization and initiate improvement projects if necessary.

3.6 Implementation

To guide the implementation process, we use the eight steps for successful change management of Kotter (1996). Kotter describes in his book eight common-made errors when changing an organization. Based on these eight errors, he formulates an eight-step process to follow in implementation processes. We briefly explain the eight-step process below.

1. Establish a sense of urgency

Identify and discuss crises or major opportunities to inspire people to move. Make objectives real and relevant.

2. Form a powerful guiding team

Get the right people in on team, with the right emotional commitment, enough power to lead the change effort, and the right mix of skills and levels. Make sure that they work together as a team.

3. Create a vision

Let the team establish a simple vision, and focus on emotional and creative aspects necessary to drive service and efficiency. Develop strategies for achieving that vision.

4. Communicate the vision

Involve as many people as possible; communicate the essence and respond to the needs of people. Teach new behaviors by the example of the guiding team.

5. Empower action

Remove obstacles, enable constructive feedback, and plenty of support from leaders. Change systems and structures that undermine the vision. Recognize and reward progress and achievements.

6. Create short-term wins

Set aims that are easy to achieve. Have a manageable number of initiatives. Finish the current stages before starting new ones. Recognize and reward employees involved in improvements.

7. Do not declare victory too soon

Foster and encourage determination and persistence for ongoing change, encourage ongoing progress reporting, and highlight achieved and future milestones. Reinvigorate the process with new projects, themes, and change agents.

8. Make change stick

Reinforce the value of successful change through recruitment, promotion, and new change leaders. Weave the change into the culture. Ensure leadership development and succession.

It is important to integrate these eight steps in the implementation process. Chapter 5 further discusses this subject. We see that it is very important to involve people and that we cannot communicate too much. Many change processes fail at the last two steps, so management of AVDS must persist in the implementation process.

4. Redesign of the MPC processes

We now know, from Chapter 2, what kind of an organization AVDS is, how AVDS is organized, and how its manufacturing departments perform. In this chapter, we aim to use the literature from Chapter 3 to construct a redesign of the MPC processes at AVDS. Section 4.1 first focuses on the order structure that AVDS uses, before we start discussing various aspects of the redesigned MPC processes. Then, Sections 4.2, 4.3, 4.4, and 4.5 discuss several modules from our framework, which we developed in Chapter 3, job planning and resource loading, combination-making, scheduling, and shop floor control, respectively. The last section, Section 4.6, focuses briefly on KPIs.

4.1 Order structure

This section focuses on the current order structure at AVDS and builds upon the discussion in Section 3.2, where we discuss relevant literature; in this section, we construct a new order structure. Our analysis in Chapter 2 makes clear that AVDS's current order structure has several disadvantages; we explain the current and new order structure and their (dis)advantages in detail in Section 4.1.1. We discuss which properties the various order types have in Section 4.1.2.

Recall that a *customer order* is placed by a customer and contains information on the specific product(s) that the customer requests, and that a *job* basically consists of a number of operations that have to be performed in different resource groups, that each job has its own routing through the manufacturing system (Pinedo, 2009), and that each job is triggered by either an actual customer order or the anticipation of a customer order (Hopp & Spearman, 2008). Further recall that a *combination* is another type of order; it relates directly to customer orders (to jobs in the new situation) and contains always one or more customer orders (or jobs) (Section 2.2.4 discussed combinations and the current combination-making process in detail).

An important question that we have to pose in this section is: "What is the operational entity that we have to control in the manufacturing system of AVDS?" Before we can answer this question, we must focus on defining what such an operational entity is. An *operational entity* traverses through the manufacturing system, on which Planning maintains control; that is, a manufacturing employee identifies a set of physical materials by the identifier of the operational entity, uses the information the operational entity provides, and works with the physical materials associated with the operational entity. *Currently*, AVDS releases customer orders to the manufacturing system and controls these and, in a later stage, customer orders are grouped into combinations. So, currently, the customer order and the combination are the operational entities that AVDS controls in the manufacturing system (where the combination is the operational entity in Digital Services, Printing, Die Cut, and Separating). In the *new* situation, we propose to use another operational entity, the *job*; this job replaces the current position of the customer order as operational entity.

4.1.1 Order structure

An order structure shows the different types of orders and the relation between them. Figure 24 depicts the current order structure and Figure 25 depicts the new order structure.

Current order structure

The current order structure (as depicted in Figure 24) consists of three types of orders; the customer order, the combination, and the batch. We previously explained the customer order and the combination, but not the batch. A *batch* is a part of one (large) customer order, where the customer order is split up into several batches. However, customer orders contain batches only sometimes (in contrast with a job, which customer orders always contain). Usually, all batches in a customer order have different internal and external due dates. Currently, a customer order contains multiple batches if, for example, the order needs to be delivered on multiple dates. Batches are only created if the customer order needs to be split up, so there are no customer order with only one batch. If a customer order contains only one batch, the batch would be redundant.

Because customer orders contain batches only sometimes, it is not possible to use the batches as the operational entity to control in the manufacturing system. So, AVDS uses the customer orders and combinations as operational entities. However, using the customer orders as an operational entity results in polluted shop floor data, because the customer orders are not unique (as we saw in Chapter 2). Unique means that it enters and exits the manufacturing system only once. A customer order essentially re-enters the system with every batch and this causes the shop floor data pollution, because all registered shop floor data from all the batches is stored under the same customer order.

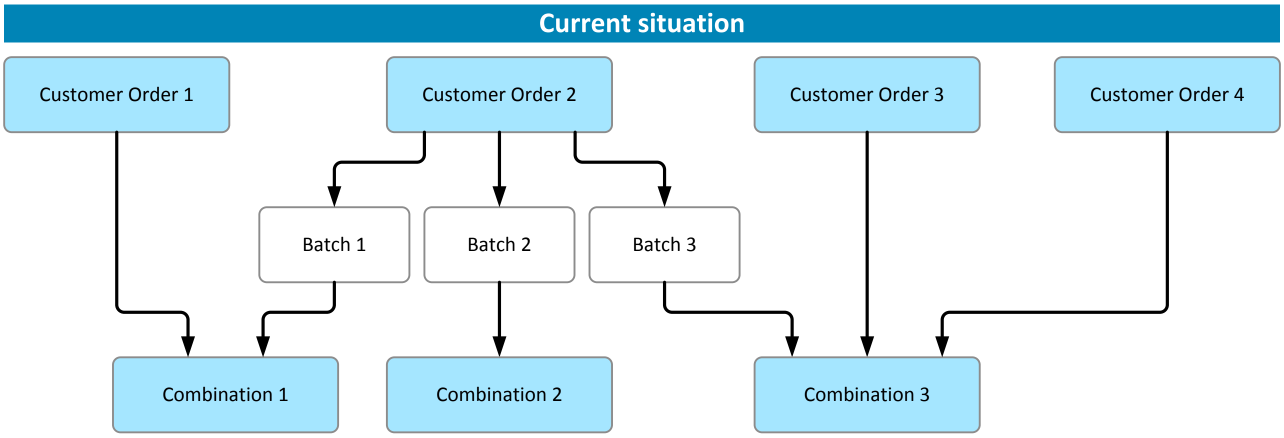


Figure 24: Example of the current order structure.

Figure 24 contains an example of several orders and combinations, representing the current order structure. It depicts the operational entities that AVDS controls in the manufacturing departments as blue rectangles and the batches, which are not operational entities, as blank rectangles. We see that customer order 2 is split up into three batches and that customer orders 1, 3, and 4 have no batches. We see further, that the three batches from customer order 2 are in three different combinations. A batch however, has no unique identifier, because it is not an operational entity. So, combination 1 contains two customer orders (customer orders 1 and 2), combination 2 contains one customer order (customer order 2), and combination 3 contains three customer orders (customer orders 2, 3, and 4). We now see the issue of shop floor data pollution arise; for example, if we want to inspect the shop floor data that was registered for, say, customer order 2, we see the shop floor data generated by the processing of all three batches, despite the fact that these were processed on different times and possibly on different resources.

New order structure

The new order structure that we propose contains a new type of order, the job. The job replaces the batch's place in the order structure, and the status of the customer order as operational entity. The latter is possible, because every customer order *must* contain at least one job. In other words, every unique set of physical materials that traverses a routing *must* have a *unique* identifier: the job number. Recall that unique means that it enters and exits the manufacturing system only once. A combination contains, logically, one or more jobs instead of customer orders.

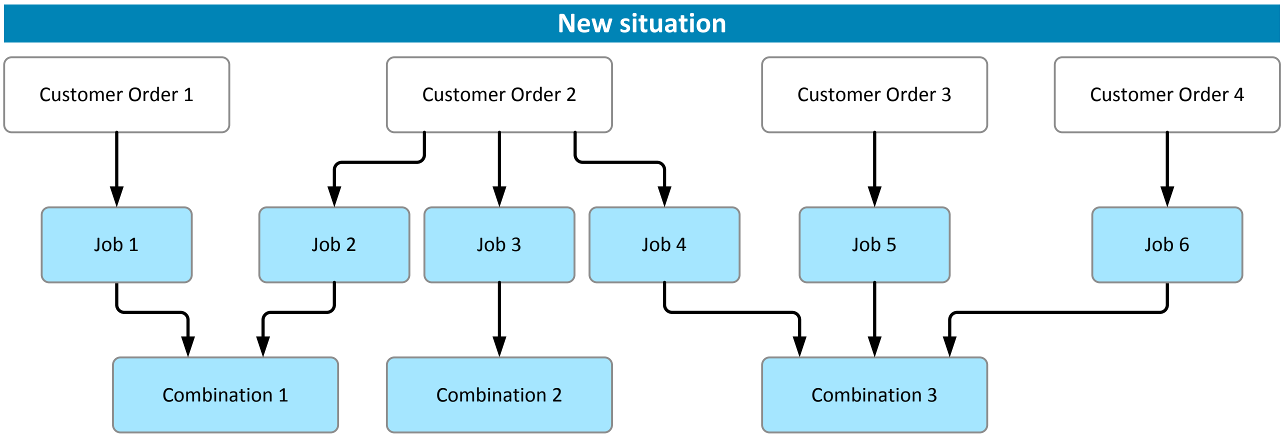


Figure 25: Example of the new order structure.

Figure 25 shows the same set of orders as in Figure 24, but now with jobs as the operational entities to control. Shop floor data is no longer linked explicitly to a customer order, but to a job. A customer order consists of one or more jobs. If we look at the shop floor data of a specific job, we see only the shop floor data related to that specific job; the shop floor data is not mixed up, as in the current situation. Another advantage of the new order structure is that it enables AVDS to use the concept of 'traceability'. Traceability means that AVDS is able to trace back, for example, for a specific product, which specific set of materials were used for it, who worked on it, etc. This ability is extremely useful when handling customer complaints.

4.1.2 Order Properties

Another distinction between the current and the new order structure lies with the properties of the order types: the customer order hierarchy. In Section 3.2, we briefly discussed properties that literature suggests. Some of these properties relate to the customer order and some to a job in a customer order.

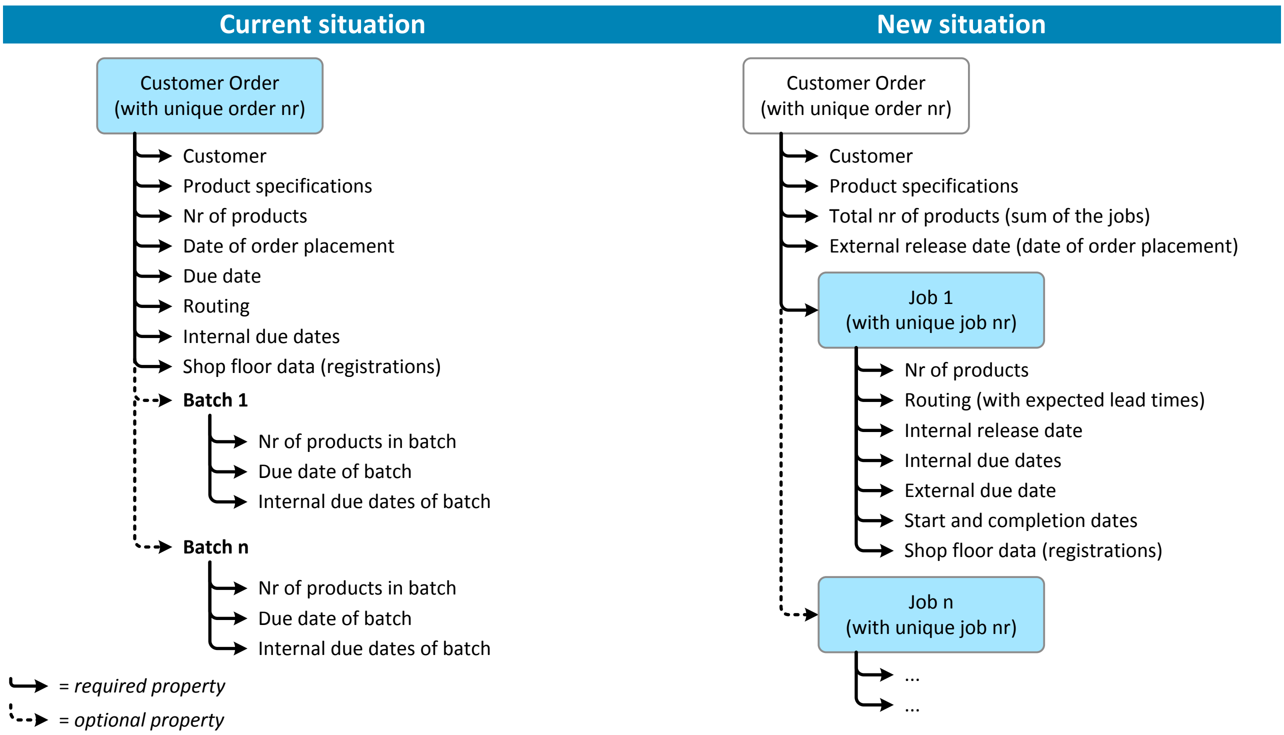


Figure 26: Customer order hierarchy, current and new.

Figure 26 depicts the current customer order hierarchy on the left and the new hierarchy on the right. Figure 26 also depicts the operational entities that AVDS controls in the manufacturing system as blue rectangles. The properties that are connected to an order type with a continuous line are required properties (the order always has this property), and the properties connected with a dotted line are optional properties (the order only has this property if required).

Currently, a customer order is a sort of repository in which all properties, related to that customer order, are gathered. So, also all data that follows from registrations in the manufacturing departments is stored with the customer order data. If an order contains multiple batches, then these are added explicitly. A batch has a few properties of its own, but inherits most of the information from the customer order (its parent in the hierarchy).

In the *new* situation however, we see that the operational entity is one level lower in the order hierarchy. The internal due dates and the shop floor data (registrations) are no longer linked directly to a customer order, but to a job (with a unique job number). With this, we disconnect the direct relation between a customer order and the shop floor (the operational execution). We can now control the manufacturing departments by focusing on jobs, which contain all the relevant information we need, and, more important, where the operational entities (jobs) are *unique*.

4.2 Job planning and resource loading

This section discusses the job planning and resource loading module of the framework from Section 0. Job planning and resource loading focuses on loading jobs to resource groups and balancing the workload in all the resource groups (Zijm, 2000). Recall that we discussed the various resource groups, currently present at AVDS, in Section 2.1.3.

The job planning and resource loading module is positioned in the tactical level of the framework and in the managerial area of resource capacity planning. This means that resource loading focuses on days to weeks ahead; it is positioned between the strategic level (focus on years) and the operational level (focus on the next couple hours to a day). The job planning and resource loading module is an important module, because if we have an unbalanced load, then the resulting schedule will be equally unbalanced, regardless of how good the schedule may be.

An important complication in the job planning and resource loading module at AVDS is *how we have to deal with combinations*. Recall that Digital Services, Printing, Die Cut, and Separating work with combinations. The most important consequence of working with combinations is that we know the exact composition of a combination only hours before production. The composition of a combination highly determines the expected processing time. For example, a combination consists of two jobs; job 1 requires 4,000 prints and job 2 requires 2,000 prints. If both jobs are placed *once* on the carton sheet of the combination (a multiplicity of 1), then we need 4,000 prints of the combination. If, however, job 1 is *twice* on the sheet and job 2 once, then we need (the maximum of 4,000/2 and 2,000) 2,000 prints of the combination.

The planning department has to steer a course between two extremes. On the one hand, it wants to know the load as soon as possible (to be able to make, for example, the short-term workforce planning in time) in Digital Services, Printing, Die Cut, and Separating (so, make combinations as early as possible), but on the other hand, it wishes to wait as long as possible to be able to make the best possible combinations (Planning has then the highest number of available jobs to combine). Planning must find a balance between these two extremes.

We propose to keep the current distinction between the manufacturing departments that work with combinations and the departments that work with jobs as the operational entity. Upon the creation of a job, its routing is known; this makes it possible to load the job already to the manufacturing departments that work with jobs. For the other manufacturing departments however, which work with combinations, the load is unknown until the definitive composition of the combination is known.

Using the combinations as the operational entity in several resource groups, creates two focal points in the entire manufacturing process, one at the moment that the operational entity changes from job to combination (at the creation of the combination) and one at the moment that it changes from combination to job (at the entry of Finishing). Figure 27 gives a clear visual representation of this. We call the moment that the combination must arrive at this point *at the latest*, the *combination due date*.

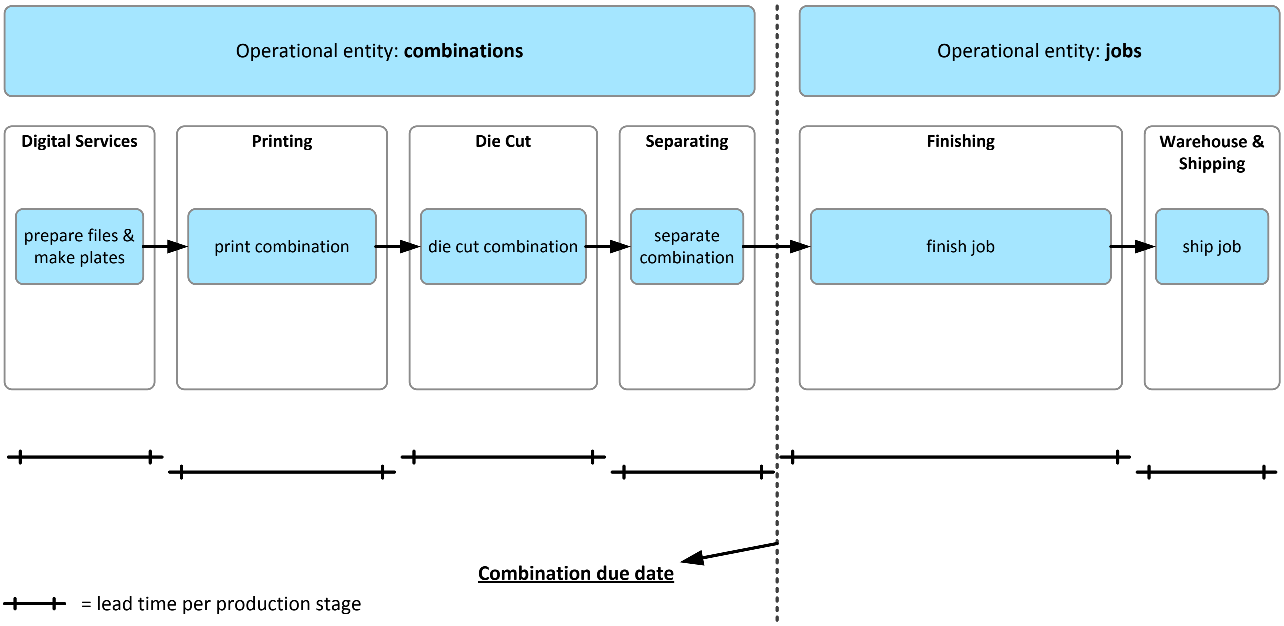


Figure 27: Combination due date in the routing of a typical job.

In Figure 27, we see the routing of a typical and straightforward job in the middle, depicted by the blue rectangles connected by arrows. For simplicity, the customer order has one process step in each manufacturing department and requires no loops through the manufacturing departments (which are depicted with blank rectangles). The horizontal lines below the departments represent the required expected lead time of the job. The large rectangles above the departments show what the operational entity is in those departments; in the Digital Services, Printing, Die Cut, and Separating departments, this is combinations, and in Finishing and Hand Assembly, jobs are the operational entity. The combination due date positions at the point in the routing where the operational entity changes from combinations to jobs.

If we calculate how much processing time the job requires in each process step in its routing, starting at the external due date and traversing through the routing backwards, we know when the job must be finished at the latest by the departments that work with combinations, the *combination due date*. This means that Digital Services, Printing, Die Cut, and Separating must process the related combination *before* the combination due date. Every combination has such a combination due date.

The IS must support the job planning and resource loading processes, to guarantee this, we organized meetings with the planners and the manager of the IS; in these meetings, we brainstormed about the required functionalities and information, and how to visualize this.

4.3 Combination-making

The previous section, Section 4.2, discussed the job planning and resource loading module; this module is closely interrelated with the module that we discuss in this section, the combination-making module. Combinations play an important role in the manufacturing processes (as we saw in Section 4.2). Recall that the departments Digital Services, Printing, Die Cut, and Separating work with combinations as the operational entity. Recall from Section 2.2.4 that a combination consists of one or more customer orders. Obviously, this will be one or more jobs in the new situation, as jobs replace customer orders in the manufacturing departments. This section focuses on the process of making combinations from a set of available jobs, in the combination-making module from our framework, and recommends AVDS how to deal with combinations. Our recommendation revolves around two aspects, the timing of the combination-making process and the software support.

Section 2.2.4 defined the optimal combination. Here, we slightly adjust this definition; in our redesign, jobs replace the customer orders in the manufacturing departments. Our definition of the optimal combination is now as follows.

> *A combination is perceived as optimal if it contains many different jobs, it has little unused surface on the sheet, and it approaches the required number of products in each job as close as possible.*

Another difference with our previous discussion on combinations is that we replace the external due date of the jobs with the combination due date. If we take the external due date into account, we disregard possible (large) differences in expected lead times in the Finishing and/or Hand Assembly departments; by using the combination due date, we solve this problem.

By making combinations, AVDS reduces the total number of set ups (and thus, the total set up time) and the number of required plates for the printing presses, as Section 2.2.4 explains. Recall that Planning does not start making combinations until 15:00 and that this results in a highly fluctuating workload at Digital Services. Furthermore, it is unacceptable that the internal or external due dates of jobs are jeopardized, because Planning waits too long before making the combinations. So, we must find a balance between waiting as long as possible, to make the best possible combinations, and waiting as little as possible, to have the largest amount of time available for the manufacturing process itself, before making the combinations.

We propose that Planning makes combinations twice a day; the first moment is at 10:00 and the second moment is at 16:00. This gives Planning the opportunity to focus on one task at a time, it spreads the time making combinations, and this gives earlier insight into the (number of) combinations that have to be processed in the coming shifts, that is, the load. The second moment is at 16:00 and is thus after the 15:00 deadline (recall from Chapter 2 that customers may place orders until 15:00), so, no new jobs, which require immediate processing, will be placed that day. In this way, we spread the – currently highly fluctuating – workload in the Digital Services department.

At the first moment of making combinations (at 10:00), Planning makes combinations from all jobs available at that time. This makes it possible that Digital Services may already start working on these new combinations. However, Planning may decide to wait with combining specific jobs, because they cannot make a good combination; it may be that a good combination would be possible, if only there would be one more of this type of job. In this (rare) case, Planning will want to wait for the possibility that such a job is created during the remainder of that day; this is allowed, except if the jobs involved need to be processed soon. At the second moment (at 16:00), however, Planning *must* combine all available jobs.

The role of software support is important; it must support the combination process through automation. Everything that can be automated, should be automated to relieve employees from labor-intensive activities and other time-consuming tasks. We saw in Section 2.2.4 that currently, little software support is available in making the combinations; the Information System (IS) accommodates making combinations, but not all required information for making combinations is readily available. As a result, the planners determine which jobs to combine into a combination by gathering information from the IS *and* the physical order tickets. Especially the latter, using information from physical order tickets instead of from the IS, is undesirable.

To collect all information the planners use in making combination, we organized meetings; in these meetings, we went through the combination-making process step-by-step with the planners, and determined which information they need. With this, we created a sketch of how the application in the IS, which supports the combination-making process, should look like. The planners should have all the information they need readily available in one application.

4.4 Scheduling

Sections 4.2 and 4.3 discussed the job planning and resource loading and combination-making modules, which are on the tactical level; this section discusses the scheduling module, which is on the offline operational level. We focus on various aspects related to scheduling; each following subsection deals with another aspect. Section 4.4.1 considers two opposites in scheduling approaches, Section 4.4.2 discusses what the use is of freezing schedules, and Section 4.4.3 explains which sequencing rules various manufacturing departments use.

4.4.1 Central versus decentral scheduling

Recall from Chapter 1 that AVDS's management envisions that a central approach to Manufacturing Planning and Control suits AVDS best; this is our restriction to the main research question. However, a decentral approach to the scheduling of individual resources may have significant advantages; so, within the scope of this one module, we consider a central and a decentral scheduling approach.

Central scheduling is that one department does all scheduling activities; so, sequencing the individual jobs per resource. Obviously, this would be the planning department. The manufacturing departments follow the schedule that Planning makes. Central scheduling has the following advantages (denoted with a plus sign) and disadvantages (denoted with a minus sign).

\+ There is one party that schedules (and is responsible for it), this enables easy communications.
\+ The manufacturing departments spend no time on scheduling tasks, which enables them to focus on their core activity: manufacturing.
\+ It is easy to adapt the schedule to short notice changes (such as, rush orders), because one party has the overview.
– The schedule is not as good as it could be; the duration of the set up times are long and highly sequence-dependent, but the manufacturing employees have more technical expertise than the planners and can determine the best sequence better. If the planners make the schedule, then not all available knowledge is used.
– Manufacturing departments are less involved with the continuous process of improving the schedule and their productivity, because Planning prescribes them what to do.

Decentral scheduling is that every manufacturing department makes its own schedule. Planning only prescribes the jobs that each manufacturing department has to process in a specific shift. So, Planning performs the resource loading and the manufacturing departments perform the scheduling activities.

+ Better schedule, we use the available knowledge of the manufacturing employees to create a schedule that has the minimum amount of total set up time.
+ More commitment of the manufacturing departments with the schedule; they make their own schedule, so they follow their own schedule (there is no one else to blame if things go wrong).
– The manufacturing departments have to spend time on scheduling; less focus on their core activity.
– It is not so easy to adapt the schedule to short notice changes (such as rush orders).

If we are to make a good decision on which scheduling approach to use, we need to look at the current situation. We saw in Section 2.4 that the manufacturing departments focus on operational performance and that planning has little priority. Especially the currently perceived importance of the schedule (or the lack thereof) by the employees in the manufacturing departments must increase. We must change the culture that planning is not important. Furthermore, the manufacturing departments have a strong focus on minimizing total set up time, which is good, but we see in Section 2.4 that this focus has become an objective in itself and even more important than the order's internal due dates, which is not good. The reason that this strong focus is there in the first place, is that the total set up time accounts for a significant amount of total available production time in several manufacturing departments (such as Printing).

We recommend AVDS to use *hybrid* central scheduling; the planning department makes the schedule and the manufacturing departments provide Planning with feedback on the schedule (see Figure 28 for a graphical representation of the new scheduling process). This means, Planning does job planning and resource loading and scheduling, but the manufacturing departments check the schedule and provide Planning with feedback on the quality of the schedule. Planning then integrates this feedback in the schedule. In this way, Planning and the manufacturing departments cooperate to come to a good schedule. The final step is that the schedule must be frozen before it goes into effect, which we discuss in Section 4.4.2.

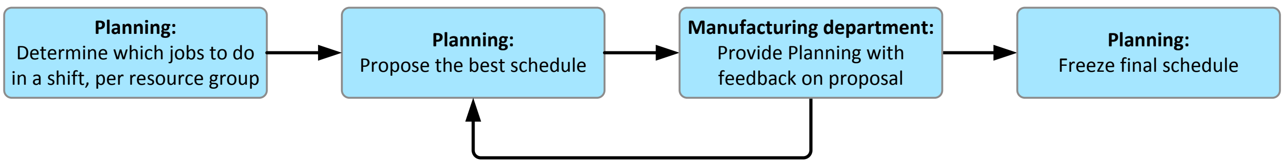


Figure 28: New scheduling process.

Figure 28 depicts the new scheduling process. It starts with Planning performing the job planning and resource loading module. Then, Planning proposes the best schedule, and the manufacturing departments provide Planning with feedback on the schedule. Planning now integrates this feedback and finally freezes the schedule.

Using this approach to central scheduling, AVDS employs the expertise that is available in the manufacturing departments, regarding what the best sequence would be, to generate a schedule that is both feasible, with respect to the internal due dates of the jobs (no unrealistic or breached internal due dates), and has as few total set up time as possible. Furthermore, AVDS keeps the employees in the manufacturing departments involved, while having a better grip on the planning at the same time.

The approach to scheduling that we propose here recognizes the significance of striving for a minimization of the total set up time, *but* in the context of trying to make a good and feasible schedule. A downside of our hybrid central scheduling approach, as explained before, is that the manufacturing departments have to spend time on checking the schedule and providing Planning with feedback; this means that they have less time to focus on their core activity (which is manufacturing). But, on the other hand, it keeps them involved with the scheduling process.

4.4.2 Frozen schedule

We have to prevent that the schedule often changes on a short notice. This would ruin the integrity of the schedule, because it would be unreliable. If a certain shift starts, then every involved party must be able to rely on the schedule.

To prevent these ad-hoc schedule changes, we schedule on a rolling horizon basis (Silver et al., 1998) and *freeze* the schedule of the first period (see Section 3.4). The frozen period ‘rolls’ forth through time. Once a schedule is frozen, it may be changed, but only with authorization of the planning department. This reduces the amount of freedom the manufacturing departments currently have in determining their own schedule.

The moment that a schedule is frozen must be before the start of the schedule. We suggest that the freezing moment is two hours before the start of the schedule. This enables the manufacturing employees to prepare the start of manufacturing, if necessary, and allows for, for example, the Warehouse and Shipping department to distribute required materials in time.

The length of the frozen period must, on the one hand, be long enough to provide Planning with the grip on the schedule they need and the manufacturing departments with clarity; on the other hand, if the frozen period is too long, then customers may place new orders that must enter the manufacturing process before the end of the frozen period, in order to be able to get it at the customer in time. The latter is due to the short delivery periods that AVDS employs and inherent to the type of business that AVDS is in. Another factor, quite practical of nature, that influences our choice of the length of the frozen period, is the working times of the planners; they work in two shifts, starting at 06:00 and ending at 22:00. As the planners are the people that make and freeze schedules, this must take place within the working hours of the planners.

We propose the length of the frozen period to be either 8 or 16 hours. A longer period is not feasible, because then new orders with a short delivery period would often disrupt the frozen schedule; a shorter period would be impractical, because then the planners would be preoccupied with making and freezing schedules. We do not choose for a continuous ‘rolling horizon’, because of our hybrid central scheduling approach; it is very intuitive for the employees in the (manufacturing) departments to have two fixed moments on a day when the schedule is frozen. Also, the current way of working focuses strongly on shifts as time buckets and we see no need to break away from this focus. Finally, with a frozen schedule of 8 or 16 hours, the manufacturing employees know exactly what they will work on in their shift, which gives them more clarity.

The frozen period is *either* 8 or 16 hours long. When the last planner goes home at 22:00, the schedule must be frozen for such a period of time that the night (from 22:00 to 6:00) and the morning (from 06:00 to 14:00) shifts know what to do. This means that the frozen period must be 16 hours. The schedule for the afternoon shift can be frozen during the morning, so then a frozen period of 8 hours suffices.

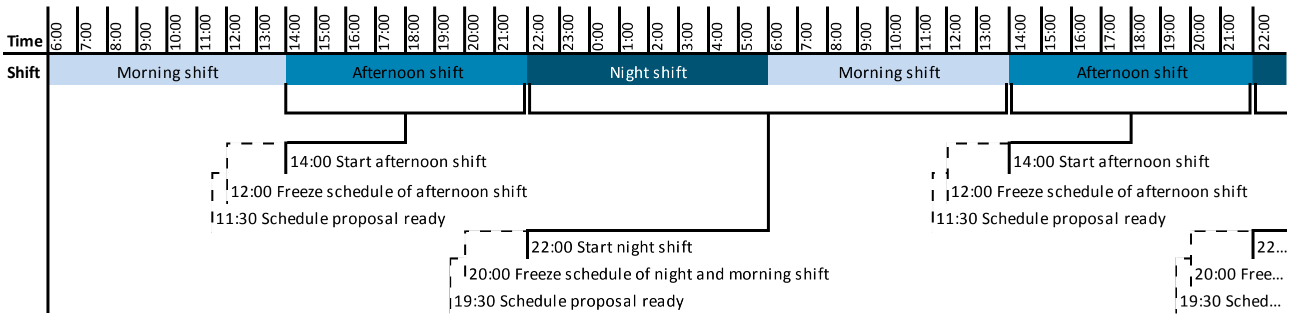


Figure 29: Timeline of freezing the schedule.

Figure 29 shows a timeline that makes clear when Planning will freeze schedules. At the top, we see a timeline, spanning a timespan that serves as an example; below the timeline, we see the three types of shifts, the morning, afternoon, and night shift. Every shift starts at predetermined times. As said, we freeze the schedule 2 hours before the shift starts and the night and the morning shift need to be frozen simultaneously. Below the shifts, the figure shows when the respective shifts start and are frozen; we see two different freeze-moments, that is, 12:00 and 20:00. For example, the afternoon shift starts at 14:00, is frozen at 12:00, and half an hour before this, Planning must have a proposal for the schedule ready. The manufacturing departments now have half an hour to provide the planning department with feedback on the quality of the schedule. We see clearly that the frozen period is 8 hours long for the afternoon shift and 16 hours for the night and the morning shift.

4.4.3 Sequencing rules

Currently, the manufacturing departments make the schedules. The previous sections discussed extensively that Planning should make the schedule and be responsible for it. To be able to do this, we provide them with a list of sequencing rules. Currently, these rules are in the heads of manufacturing employees and planners. This section lists relevant sequencing rules and prioritizes these rules. We discuss every manufacturing department and the rules they use to make a schedule. These rules describe which sequence of jobs is preferable, but within the restrictions imposed by the job planning and resource loading module.

Printing

Printing uses the following sequencing rules to sequence the combinations (recall that Printing works with combinations); we list the rules according to their importance; for example, rule 1 is more important than rule 2.

1. *Group combinations with the same material type:* the set up time reduces significantly if the material type of two consecutive combinations is the same.
2. *Sort combinations such that the material size of consecutive combinations decreases:* a material switch to a larger size of material requires more set up time than a switch to a smaller material.
3. *Group the types of coating:* each switch between coating type (for example, gloss or matted coating) requires extra set up time.
4. *Group combinations that require similar inks to be used:* a printing press needs to be cleaned before and after, for example, a specific PMS ink (inks that are already blended to match exact color requirements), so grouping combinations that require similar inks, reduces the total set up time.

Die Cut

The sequencing rules in Die Cut are less complicated than in Printing; the rules focus solely on the dies that the combinations require. They use a die to cut the contour of the products in the sheets, such that Separating can remove surplus materials and separate the individual jobs. Die Cut requires for each product a die; so, Die Cut requires one or more dies for every combination. The rules are as follows.

1. *Group combinations with the same die(s):* Set up time reduces if the same die(s) is in two consecutive combinations.
2. *Sort combinations such that the die(s) stays on the same position in the machine, if possible:* if the die(s) can remain on the same position in the machine, this reduces set up time significantly.

Separating

At the Separating department, the sequence of the combinations is irrelevant. This is due to the fact that there are no machines that require a set up; the set up time is always zero. This means that, within the boundaries set by job planning and resource loading, the sequence of combinations has no influence on the lead times of the combinations.

Finishing

For the Finishing department, the rules concern the products specifications and the external due date. Because Finishing is often the last department in the routing, time pressure is highest in this department. The sequencing rules are as follows.

1. *Give priority to jobs that run late:* if the job runs late, it obviously has priority over jobs that are in time.
2. *Sort jobs with the product specification as close as possible:* Set up time of a machine is smaller if the product specification is the same or comparable to the previous job.

Hand Assembly

As with Separating, Hand Assembly has zero set up times. The work that Hand Assembly does cannot be done by machines in the Finishing department; this means that the work must be done by hand. In the case of Hand Assembly, this results in a zero set up time. So, the sequence of jobs at Hand Assembly is irrelevant.

AVDS has often products that differ from standard products. This means that the above sequencing rules form a basis of making a schedule; a lot of fine-tuning must be done by the planning department after applying these rules. The characteristics of the jobs may lead Planning to deviate from these rules, because, for example, product variants (different orders, but the same product with text in another language) are always processed successively, if possible. We perceive that automating the scheduling function is possible, but only to a certain extent, while the planners do the fine-tuning of such a schedule.

4.5 Shop floor control

Where the job planning and resource loading and combination-making modules are on the tactical level, and the scheduling module on the offline operational level, the shop floor control module coordinates the activities of the resource groups in real-time, thus is on the online operational level. This section concentrates on this module and how AVDS should use it to respond to disruptions in the manufacturing departments.

In accordance with the restriction that we have on the main research question in Section 1.3, AVDS should use a central control approach, where the planning department forms the central authority that monitors the activities in the manufacturing departments and their resources.

Although we see in the previous section, Section 4.4, that we need to freeze the schedule, we also need the flexibility that enables Planning and the manufacturing departments to cope with disruptions that arise during the manufacturing process. However, the challenge is to keep the integrity of the frozen schedule intact; we cannot afford people to think that the frozen schedule is not actually frozen, but that things can still be shuffled at will, as is currently the situation. The consequence of the latter line of reasoning will be that AVDS returns, with the newly redesigned MPC processes, to the current situation, where the schedule means little. It is unrealistic to think that a frozen schedule needs no ad-hoc adjustments; for example, raw material may be unavailable when a resource needs it, a rush job may require immediate processing, or the actual processing time of a job is longer than expected. Many more disruptions may force Planning to adjust the schedule on short notice, despite the fact that it is frozen. The trick is to allow for schedule changes in such a way that manufacturing employees do not get the impression that making a schedule change has no strings attached.

A schedule change occurs if someone deviates from the schedule in terms of job sequence or times. In two different situations a schedule change occurs: (1) the job sequence changes and (2) the time that the job can start or finish changes.

We use a formal channel to enable schedule changes, to control and limit the amount of schedule changes, as shown in Figure 30. If a manufacturing employee sees the need to deviate from the schedule, then he or she contacts the planning department, but not in all deviations; if the deviation is small, then the employee should cope with it himself. We formulate the following rule, which states when an employee should contact Planning.

> *Planning should be contacted if a deviation from schedule causes a change in the job sequence or when an internal due date of a job is endangered.*

Planning must then authorize the schedule change. If authorized, the manufacturing employee must register the reason for the schedule change. If no planner is present (such as, during a night shift), then the employee may make the schedule change, but he or she must also register the reason for the schedule change. Upon return, the planners review the schedule changes that were made in their absence and may ask the employees that made a change, for their motives.

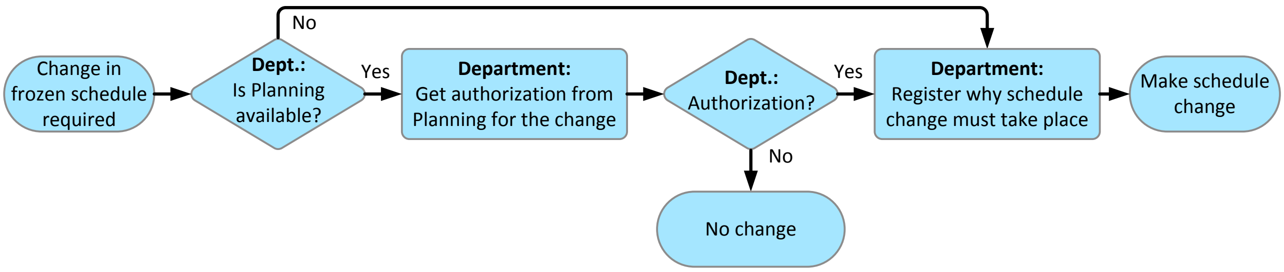


Figure 30: Adjusting a frozen schedule.

Figure 30 shows in a flowchart how the schedule may be changed, once it is frozen. Two main principles emanate from the flowchart: (1) Planning is the authority with respect to the schedule and (2) schedule changes must be registered. The flowchart in Figure 30 starts with a need for a change in the frozen schedule (a major deviation). Then an employee of the department that has this need, contacts Planning and requests the change (if not available, then the employee may skip the authorization step). If Planning authorizes the change, then the employee may continue and register the reason for the schedule change. Once this is done, the department may deviate from the frozen schedule.

This concludes our discussion of the four planning modules, job planning and resource loading, combination-making, scheduling, and shop floor control, which we discussed in Sections 4.2, 4.3, 4.4, and this section (4.5), respectively. We explained that Planning is responsible for each of these modules and performs most of the tasks in the modules; in the scheduling module, the manufacturing departments provide Planning with feedback on proposed schedules.

4.6 Key Performance Indicators

This section discusses Key Performance Indictators (KPIs). Recall from Section 3.5 that a KPI reflects the organization's vision and strategy, is easy to interpret and actionable, decided by management, and tied to roles, processes, system capabilities, and products/services of the organization (Ganesan & Paturi, 2009). Especially the first aspect (a KPI reflects the organization's vision and strategy) is the part where we think AVDS misses out.

In the KPIs that AVDS employs is no KPI that focuses on the performance of departments with respect to the planning. In the shop floor data analysis, which we performed in Section 2.4, we saw the results of this. AVDS's management must encourage the manufacturing departments to follow the schedule, and the use of KPIs is a powerful tool in encouraging manufacturing departments.

We suggest that AVDS's management introduces one or more KPIs that focus on the planning. Two KPIs that would be suitable candidates are as follows.

1. Internal delivery reliability of a manufacturing department.
2. Average lateness of late orders.

The first concerns the internal delivery reliability of a manufacturing department. This reflects how often the department finishes an order before the internal due date that Planning sets. Basically, the manufacturing departments are suppliers of each other. Then, this is an obvious KPI to use.

The second KPI focuses on the average lateness of *late* orders. Orders that were in time are not involved; the KPI shows the average delay of a late order and gives insight in the severity of an average delay.

5. Implementation plan

We now discuss how our redesign should be implemented, in order to guarantee future success. In this chapter, we focus on the implementation phases at AVDS. First, we focus on the implementation plan itself in Section 5.1. Then, we construct a pilot plan in Section 5.2. We analyze the results of the pilot in Section 5.3.

5.1 Implementation plan

We use the eight-step process of Kotter (1996) as the basis of our implementation plan. This section constructs an implementation plan that guides the implementation of the redesigned MPC processes at AVDS. Recall that Kotter's eight-step process is as follows.

1. *Establish a sense of urgency*
2. *Form a powerful guiding team*
3. *Create a vision*
4. *Communicate the vision*
5. *Empower action*
6. *Create short-term wins*
7. *Do not declare victory too soon*
8. *Make change stick*

We already performed several steps that Kotter (1996) suggests. The first step, establish a sense of urgency, was prepared during the last couple of years, because everybody saw that planning had to be done better; the start of our graduation project functioned as a catalyst of this step. With forming the project team, we stimulated the sense of urgency even more and formed a powerful guiding team, which is step 2, because we involved all key stakeholders of the planning project. In the meetings of the project group, we presented and discussed our observations and the analysis of the shop floor data; together with the project team, we formed a vision (step 3) of where we wanted to go in redesigning the MPC processes. We communicated this in other meetings and informal conversations to other employees in the manufacturing departments, which is step 4.

To perform step 5, empower action, we construct a plan for a pilot in the Printing department in Section 5.2, and evaluate the pilot in Section 5.3. With the pilot, we test our redesign, prepare for a full-scale implementation of the redesigned MPC processes, and, most importantly, gather feedback of the manufacturing employees and involve them in the change process.

AVDS is still to arrive at steps 6, 7, and 8, and is still a long way of completing the implementation process. Finishing it and changing the culture requires a long breath of AVDS's management. However, if management of AVDS manages to stick to Kotter´s 8-step change process and keeps communicating to people, the implementation of the redesigned MPC processes should succeed.

5.2 Pilot plan

This section constructs the plan for a pilot in the Printing department. By performing a pilot with the new scheduling process, we can search for flaws in the new processes and prepare for a full-scale implementation. We also empower action (step 5 of the implementation plan), which is an important part of the implementation process. Sections 5.2.1 to 5.2.5 discuss the scheduling process itself, the various responsibilities, the process of adjusting a frozen schedule, the duration of the pilot, and the performance measurements, respectively.

5.2.1 Making the schedule

The first step in constructing the pilot is to define how the scheduling process will be executed. Section 4.4 discussed the redesigned scheduling process; here, we apply it specifically to the Printing department (see Figure 31).

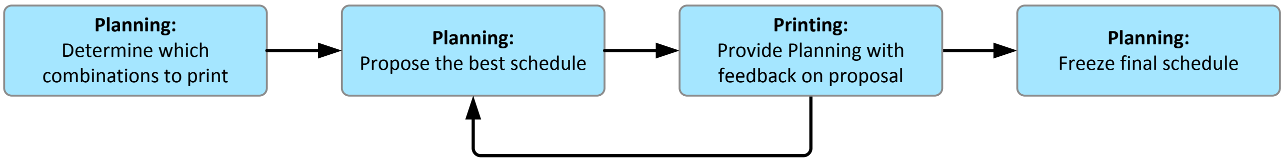


Figure 31: The scheduling process in the pilot.

Figure 31 resembles the scheduling process as described in Section 4.4, but is applied specifically to Printing, as the pilot will run in this manufacturing department. Printing and Planning cooperate to make a good schedule. First, Planning determines which combinations have to be printed in the next shift(s). Then, Planning proposes a schedule to Printing, Printing checks this proposal, and gives Planning its feedback on this proposal. Finally, Planning implements the feedback and freezes the schedule.

The scheduling process is executed at predetermined times, as we recall from Section 4.4. However, we change the freezing time for the schedule of the night and morning shifts in the pilot, because of the current working times of some people that are involved (it is a vacation period); we change this freezing time to 18:00 (was 20:00). So, Planning freezes the schedule for the afternoon shift at 12:00 and the schedule for the night and morning shifts at 18:00. See Figure 32 for the adjusted timeline.

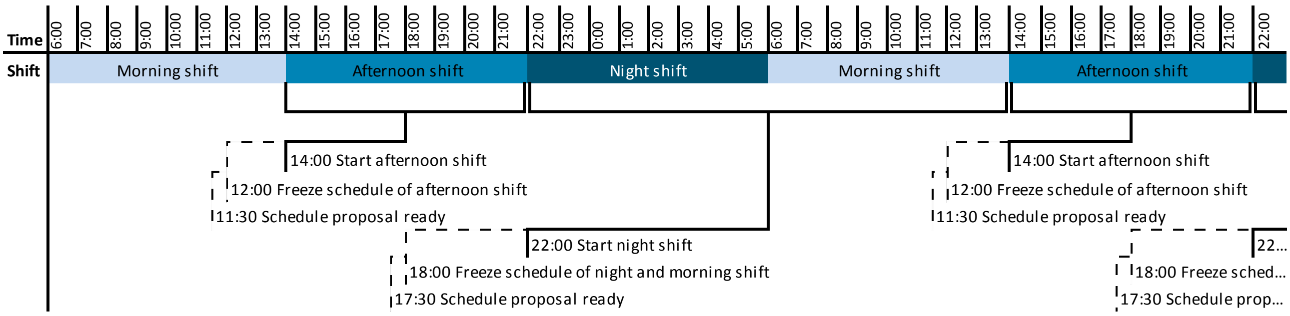


Figure 32: Timeline of freezing the schedule in the pilot.

We see in Figure 32 that the schedule for the Printing department will be frozen at 12:00 and 18:00. The Printing department has half an hour before that to examine the proposal of Planning and provide Planning with feedback. Obviously, Planning must have made a proposal before this.

5.2.2 Responsibilities

It must be clear who is responsible for what. This section aims to give an overview of the responsibilities and describes who is involved. Table 3 summarizes the responsibilities during the pilot, and the remainder of this section discusses these responsibilities.

Responsibility	Responsible party/person
Make and propose schedule in time	Planning department
Provide Planning with feedback on schedule in time	Team leaders of Printing
Freeze the schedule in time	Planning department

Table 3: Responsibilities in the pilot.

The planning department is the authority that controls the schedule. This means that Planning holds the final responsibility for ensuring that the schedule is available in time. In this pilot, we involve the two planners that are currently already involved in the Printing department (see Section 2.1). The third planner currently plans and controls the Finishing department and will be involved at a later moment.

The team leaders of the Printing department must provide Planning with feedback on the proposed schedule. They determine whether the schedule minimizes the total set up time and is feasible. Their feedback consists of change suggestions in the proposed schedule that will decrease the total set up time, or otherwise improve the schedule, in the Printing department.

Finally, Planning must freeze the schedule in time; the planners should include the feedback from Printing in the frozen schedule, if sensible. The timeline is important to follow and even Planning must do as agreed. Every party must know the frozen schedule in time and Planning should guarantee this.

5.2.3 Adjusting a frozen schedule

If the need arises to change the frozen schedule (a major deviation occurs), this must be possible. It is not, however, without any strings attached, as in the current situation. In the pilot, we follow the same procedure as described in Section 4.5 to change a frozen schedule. Figure 33 shows the procedure, but now specifically applied to the Printing department.

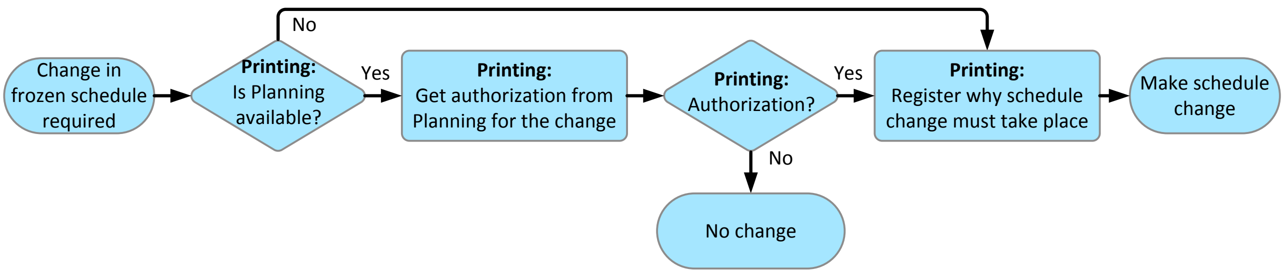


Figure 33: Adjusting a frozen schedule in the pilot.

The process in Figure 33 starts when Printing has a reason to change the frozen schedule (like, for example, the material is unavailable for the next combination in the schedule). Printing then contacts Planning, requests authorization, and – upon approval – registers the reason for the schedule change. If this is done, the schedule is changed.

5.2.4 Duration of the pilot

The length of the pilot must be such that we are able to compare the results of the pilot with other sets of shop floor data. However, it cannot be too long, because of the limited time available in this graduation project. The pilot will run for 3 weeks: from Monday 17 July 2012 until Friday 3 August 2012. At the end of these 3 weeks, we evaluate the pilot.

5.2.5 Measuring improvements

To know whether the pilot improves anything, we must measure the performance of the Printing department during the pilot. This section discusses how we measure this performance. We have various sources that provide us with information on this performance; we discuss each of our three measurement tools in the remainder of this section.

Our first performance measurement tool is the analysis as we described in Section 2.4. This analysis tool uses the shop floor data, which follows from registration at the manufacturing departments, to calculate various performance measures (such as the number of combinations that leave Printing later than its internal due date for Printing).

The second performance measurement tool is the set of KPIs that AVDS uses to monitor several aspects of the performance of its departments. Recall that AVDS uses three KPIs on organizational (recovery orders, internal rejects, late deliveries, and external rejects) and two on departmental level (average run speed and average set up time). An advantage of using the KPIs to measure the performance is that we can compare the data from the pilot with the complete history of these KPIs.

Next to measuring the performance of the Printing department, our third measurement tool focuses on how the involved parties follow the plan of the pilot, whether the redesigned scheduling process works as expected, and how often a frozen schedule is changed. The latter should be exceptional, because everyone should be able to rely on a schedule, once frozen. We use a registration form (see Appendix H) that the team leaders and planners should fill in during production. Through the use of the registration form, we can evaluate the following aspects of the redesigned scheduling process:

- the timeliness of Planning in proposing the schedule;
- the amount of changes that Printing suggest for the proposed schedule;
- the timeliness of Planning in freezing the schedule; and
- the number of and the reasons for frozen schedule changes.

5.3 Pilot results

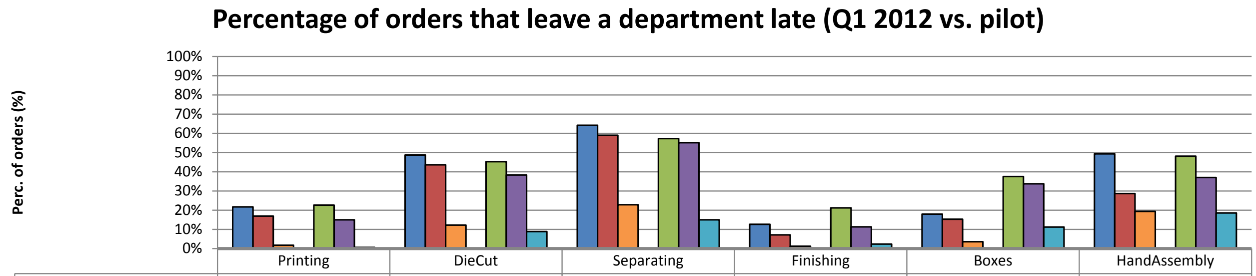
We now have a redesign of the MPC processes at AVDS, as we discussed in Chapter 4, and a plan to do a pilot run of this redesign in the Printing department, as discussed in Section 5.2. This section focuses on the next step, determine whether the redesign of the MPC processes results in an improved performance of the manufacturing departments and – ultimately – in improved delivery reliability. Recall from Chapter 1 that the latter was the motivation of AVDS to initiate this project. The remainder of this section focuses on the three performance measurement tools as explained in Section 5.2.5, these are, (1) our shop floor data analysis, (2) AVDS's KPIs, and (3) results from the registration forms.

The pilot, as constructed in Section 5.2, is performed at AVDS in the Printing department from 17 July 2012 until 3 August 2012. During this period of three weeks, Planning and Printing followed our pilot plan.

5.3.1 Results shop floor data analysis

Here, we evaluate the pilot by performing the same analysis as we did in Section 2.4. In the results, we focus on the Printing department, as we performed the pilot in this department. We discussed the results of the analysis of the first quarter of 2012, the current situation, in Section 2.4; Appendix G contains an overview of all these results.

The first and most important result from the shop floor data analysis of the pilot is the percentage of orders that left a department late during the pilot (see Figure 34).



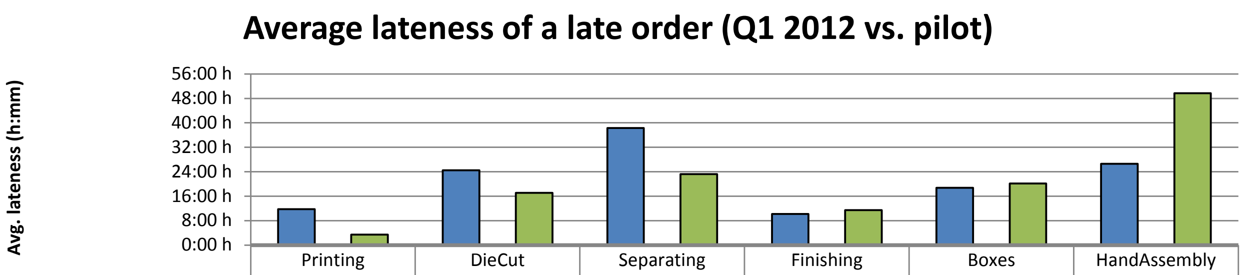
	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
% orders late (Q1 '12)	21.76%	48.67%	64.21%	12.67%	17.94%	49.33%
% orders >2h late (Q1 '12)	16.97%	43.62%	59.00%	7.13%	15.25%	28.67%
% orders >24h late (Q1 '12)	1.74%	12.27%	22.89%	1.26%	3.59%	19.33%
% orders late (pilot)	22.59%	45.21%	57.26%	21.19%	37.50%	48.15%
% orders >2h late (pilot)	14.95%	38.36%	55.13%	11.29%	33.75%	37.04%
% orders >24h late (pilot)	0.66%	8.90%	14.96%	2.38%	11.25%	18.52%

Department

Figure 34: Percentage of orders that left a department late during the pilot.

Figure 34 consists the percentage of late orders for six departments in the 'current situation' (Q1 of 2012) and during the pilot. For every department in the figure, it shows the percentage of orders that were late, more than 2 hours late, and more than 24 hours late, for both during Q1 2012 and during the pilot.

In Printing, 22.59%, 14.95%, and 0.66% orders were late, more than 2 hours late, and more than 24 hours late, respectively. In Q1 of 2012, this was 21.76%, 16.97%, and 1.74%. We see primarily a decrease of orders that were more than 24 hours late. Die Cut and Separating, which are closely related to Printing, also perform better. Finishing, Boxes, and Hand Assembly scored worse than in Q1 of 2012, because these departments were struggling with getting sufficient personnel (the pilot was performed during a period in which many employees were on vacation) and multiple (severe) operational problems with materials. Also, during the pilot, the number of customer orders increased, because of the high season that is on its way.

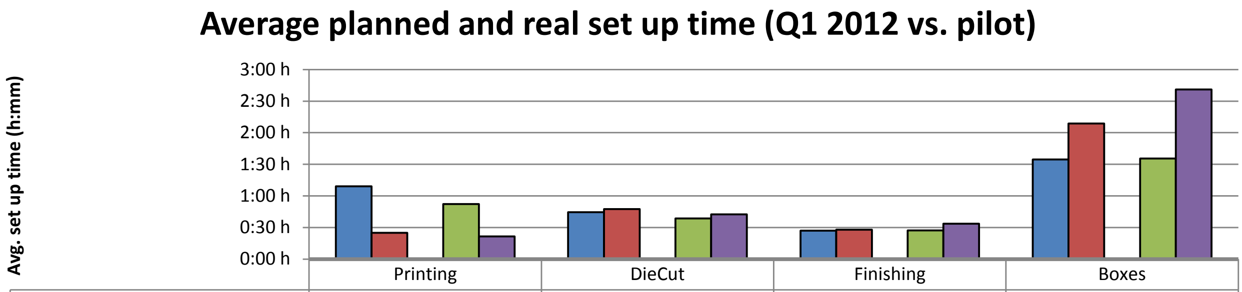


	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
Average time late (Q1 '12)	11:45 h	24:27 h	38:19 h	10:12 h	18:43 h	26:36 h
Average time late (pilot)	3:28 h	17:06 h	23:13 h	11:25 h	20:12 h	49:41 h

Department

Figure 35: Average lateness of a late order during the pilot.

Figure 35 shows the average lateness of a late order during Q1 of 2012 and the pilot. If an order is late, then, on average, it was 3:28 hours (3 hours and 28 minutes) late in Printing during the pilot. In our previous analysis this was 11:45 hours. This is a major decrease in average lateness and means that the average delay of a late order decreased. We see this effect also in Figure 34, where the number of orders that were more than 2 hours and 24 hours late decreased. This effect propagates to the consecutive departments; Die Cut was 24:27 hours and is now 17:06 hours, Separating was 38:19 hours and is now 23:13 hours. We see in Figure 35 again the reduced performance of Finishing, Boxes, and Hand Assembly.

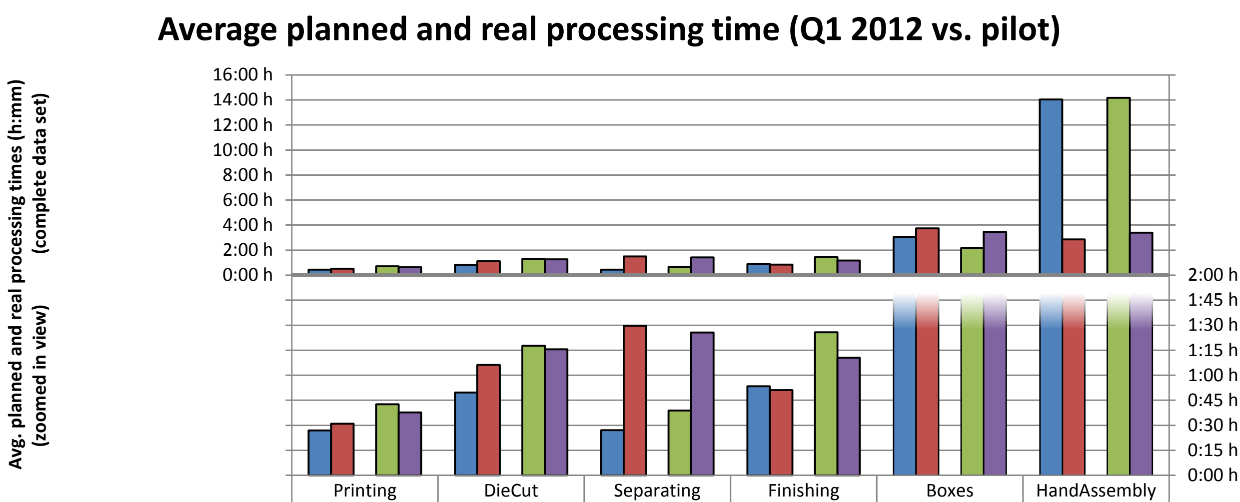


	Printing	DieCut	Finishing	Boxes
Avg. planned set up time (Q1 '12)	1:09 h	0:44 h	0:26 h	1:34 h
Avg. real set up time (Q1 '12)	0:25 h	0:47 h	0:27 h	2:08 h
Avg. planned set up time (pilot)	0:52 h	0:38 h	0:27 h	1:35 h
Avg. real set up time (pilot)	0:21 h	0:42 h	0:33 h	2:41 h

Department

Figure 36: Average planned and real set up time during the pilot.

Figure 36 focuses on the average set up times in Printing, Die Cut, Finishing, and Boxes; it compares the average planned and real duration of set up times during the first quarter of 2012 and during the pilot. Surprisingly, the average set up time in Printing reduced from 1:09 hours planned and 0:25 hours real (in our previous analysis) to 0:52 hours planned and 0:21 hours real. Especially the average real set up time is interesting; we expected this to increase, because the scheduling module is more centralized in the redesign. Because the planners have less technical expertise to determine the best schedule, it could be less optimal. Apparently the feedback from Printing on the schedule compensates for this. Freezing the schedule may also contribute, because this reduces/diminishes the amount of ad-hoc schedule changes. There is still, however, a large discrepancy between the planned and real set up time. This is because of the fact that the planned set up time is handled as constant in the IS, but is in fact highly sequence-dependent. Die Cut also performs slightly better with respect to the average planned and real set up times.

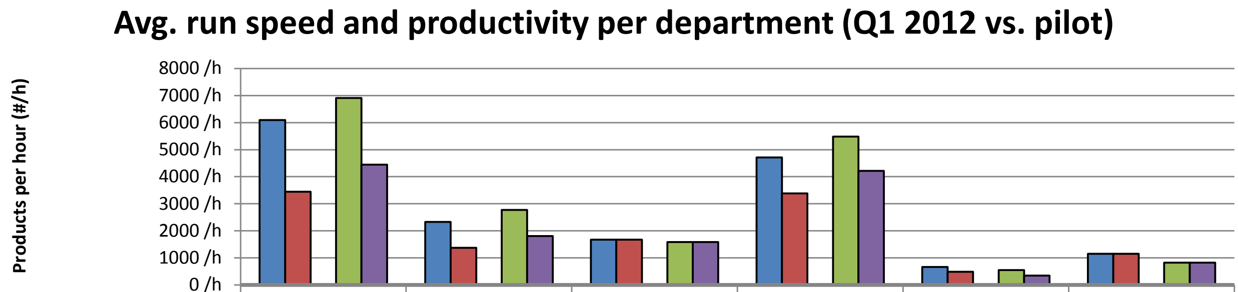


	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
Avg. planned proc. time (Q1 '12)	0:26 h	0:49 h	0:27 h	0:53 h	3:02 h	14:02 h
Avg. real proc. time (Q1 '12)	0:30 h	1:06 h	1:29 h	0:51 h	3:44 h	2:51 h
Avg. planned proc. time (pilot)	0:42 h	1:17 h	0:38 h	1:25 h	2:10 h	14:10 h
Avg. real proc. time (pilot)	0:37 h	1:15 h	1:25 h	1:10 h	3:26 h	3:23 h

Department

Figure 37: Average planned and real processing time during the pilot.

Figure 37 focuses on the average planned and real processing time during Q1 of 2012 and during the pilot. It consists of two panels, where the top panel shows the complete data set and the lower panel shows a zoomed in view, because of the large differences between the departments. The zoomed in view is restricted to 0 to 2 hours, where a fade-out of the bar depicts that the data continues outside this view. The averages in Figure 37 are higher than in our previous analysis. This is due to the specific order mix in the period of the pilot (more large orders, which means that the printing presses can run on full speed for a longer period of time). The differences between planned and real processing times, however, are more or less equal with Q1 of 2012. We see that, apart from Separating and Hand Assembly, the planned processing times approach the real processing times fairly well. Separating still registers poorly, and the peak at Hand Assembly is still there (no surprises here, because these problems are not addressed yet), which, as we recall from Chapter 2, is caused by the simplistic estimation method of the required processing time at Hand Assembly.



	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
Avg. run speed (Q1 '12)	6094 /h	2330 /h	1673 /h	4715 /h	666 /h	1153 /h
Avg. productivity (Q1 '12)	3447 /h	1375 /h	1673 /h	3385 /h	488 /h	1153 /h
Avg. run speed (pilot)	6907 /h	2773 /h	1583 /h	5486 /h	556 /h	827 /h
Avg. productivity (pilot)	4451 /h	1810 /h	1583 /h	4219 /h	346 /h	827 /h

Department

Figure 38: Average run speed and productivity per department during the pilot.

Figure 38 shows the average run speed and productivity in each department (see Section 1.6 for the definitions) during Q1 of 2012 and during the pilot. The run speed in the departments is more or less equal to those in our previous analysis, but the productivity is different. In the departments Printing and Die Cut, the productivity increased from 3,447 to 4,451 products per hour and from 1,375 to 1,810 products per hour, respectively. This is an increase of 29% in Printing and 32% in Die Cut. This may be because of the increased average real processing time (longer run lengths), and because of an improved schedule (and thus, better MPC processes).

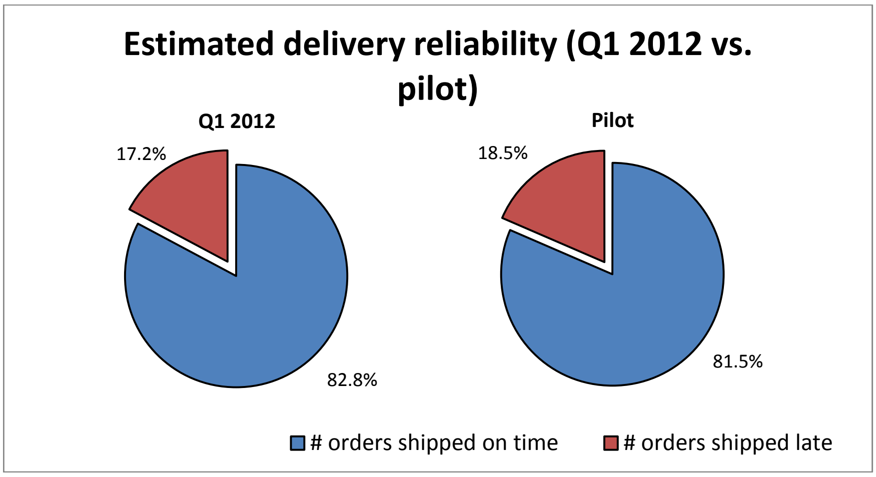


Figure 39: Estimated delivery reliability during the pilot.

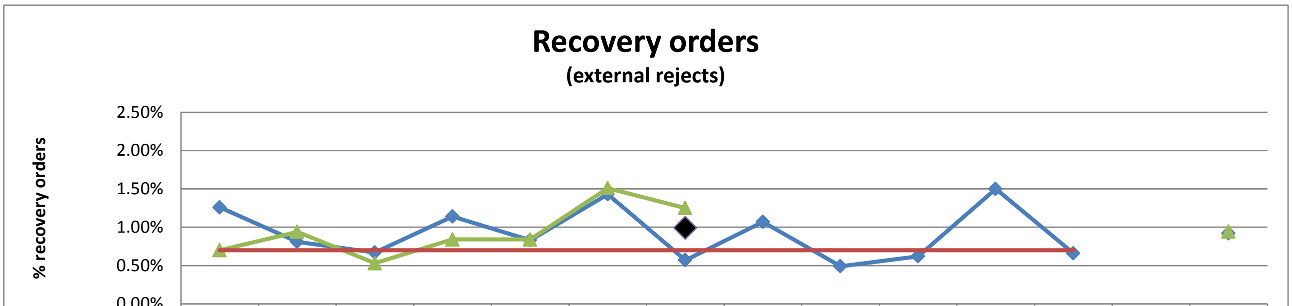
Figure 39 estimates what delivery reliability would be. To calculate this, we determine for each order when the last registration in the manufacturing department was and when the order should be delivered to the customer. Then we add 48 hours (the duration of regular transportation) to the time of the last registration. If the latter is later than the delivery date of the order, then the order is shipped late. The estimated delivery reliability is the percentage of orders that were shipped in time. This is a quite rough method and has many disadvantages. However, it does provide us with insight into how much buffer AVDS has at the end of manufacturing processes. The estimated delivery reliability is 81.5%, this was 82.8% in our previous analysis; it is slightly worse. We expected this before performing the analysis, because of the many (severe) operational problems that Finishing and Hand Assembly encountered during the pilot. AVDS currently improves this estimated delivery reliability by employing faster and more expensive transportation to get the orders in time at the customer after all.

5.3.2 Results KPIs

Next to the results from the shop floor data analysis, we have the key performance indicators that AVDS reports monthly. We discuss the results of these KPI for the specific time interval of the pilot hereafter. We compare the previous performance with that during the pilot. We first discuss the KPIs on the organizational level and then those on departmental level for the Printing department.

Organizational level

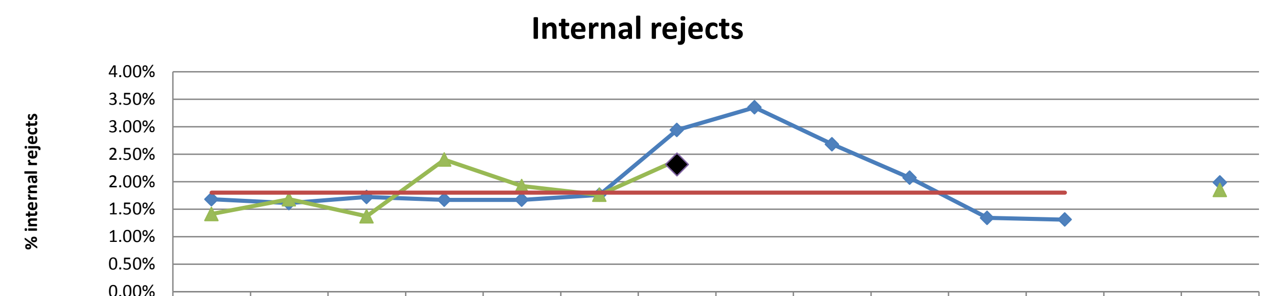
We now take a look at the KPIs that AVDS employs on the organizational level.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec		Avg
2011	1.26%	0.81%	0.67%	1.14%	0.83%	1.43%	0.57%	1.07%	0.49%	0.62%	1.50%	0.66%		0.92%
2012	0.70%	0.94%	0.53%	0.84%	0.84%	1.51%	1.25%							0.94%
Target 2012	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%	0.70%		0.70%
Results pilot							0.99%							

Figure 40: KPI recovery orders during pilot.

Figure 40 shows the percentage of recovery orders during a period. We see that in July, 1.25% of all orders were recovery orders. A recovery order may occur because, for example, not enough products were delivered to the customer and more must be made. During the pilot, there were fewer recovery orders, that is 0.99%. Recall that the pilot was from 17 July until 3 August.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec		Avg
2011	1.68%	1.61%	1.72%	1.67%	1.67%	1.76%	2.94%	3.35%	2.68%	2.07%	1.34%	1.31%		1.98%
2012	1.41%	1.68%	1.37%	2.40%	1.92%	1.76%	2.39%							1.85%
Target 2012	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%	1.80%		1.80%
Results pilot							2.31%							

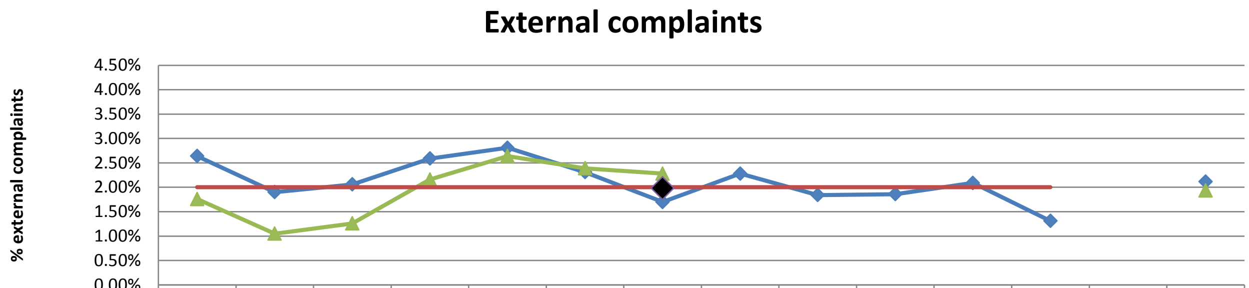
Figure 41: KPI internal rejects during pilot.

In Figure 41, we see the percentage of internal rejects. An internal rejects may be caused by, for example, poor performance of the products in an order, which is identified *within* AVDS. The performance in July and during the pilot is equivalent, and better than in July 2011. This year, AVDS has fewer orders.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec		Avg
2011	2.28%	1.90%	2.60%	1.90%	1.90%	1.21%	4.45%	5.94%	2.90%	3.16%	2.01%	1.53%		2.65%
2012	2.35%	0.94%	1.37%	1.80%	1.44%	0.38%	1.48%							1.39%
Target 2012	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%		2.00%
Results pilot							1.65%							

Figure 42: KPI late deliveries during pilot.

In Figure 42, we see an enormous peak in the graph for 2011; this year, AVDS performs significantly better. The peak is a yearly returning problem at AVDS, as we explained in Section 2.3; in July, many employees go on vacation, and directly after that, with the troubles of the vacation period still present, the high season starts, with the accompanying increase of new orders. The performance in 2012, with respect to the late deliveries, is better and under the maximum limit (the target for 2012 is a maximum of 2% late deliveries); this is for a large part due to the fact that AVDS has less orders than the previous years, another cause is the redesigned MPC processes. In conversations with the manufacturing employees and planners, we hear frequently that these people perceive that the workload is more balanced than before the pilot and that more orders arrive in time on the manufacturing department.



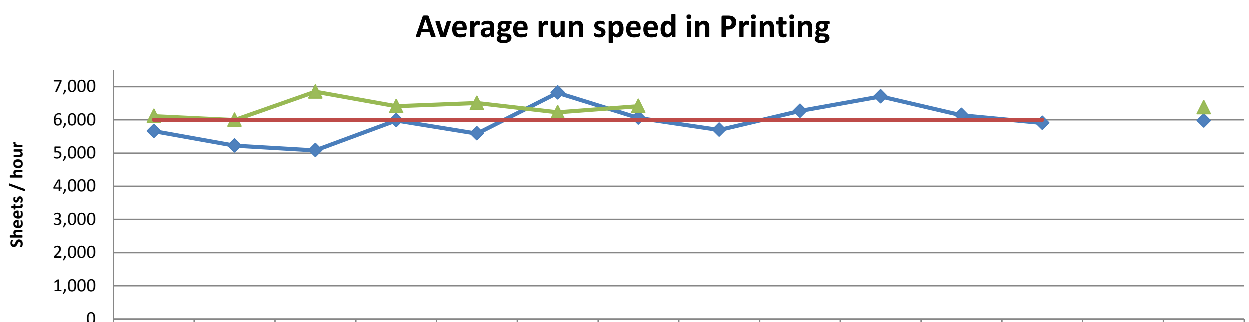
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec		Avg
2011	2.64%	1.90%	2.06%	2.59%	2.81%	2.31%	1.70%	2.28%	1.84%	1.86%	2.09%	1.31%		2.12%
2012	1.76%	1.05%	1.26%	2.16%	2.64%	2.39%	2.28%							1.93%
Target 2012	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%		2.00%
Results pilot							1.98%							

Figure 43: KPI external complaints during pilot.

Figure 43 presents the results of the KPI external complaints. External complaints almost always concern quality issues of products. This has little to do with planning, so we expected little difference in this KPI during the pilot. The results confirm this observation.

Departmental level

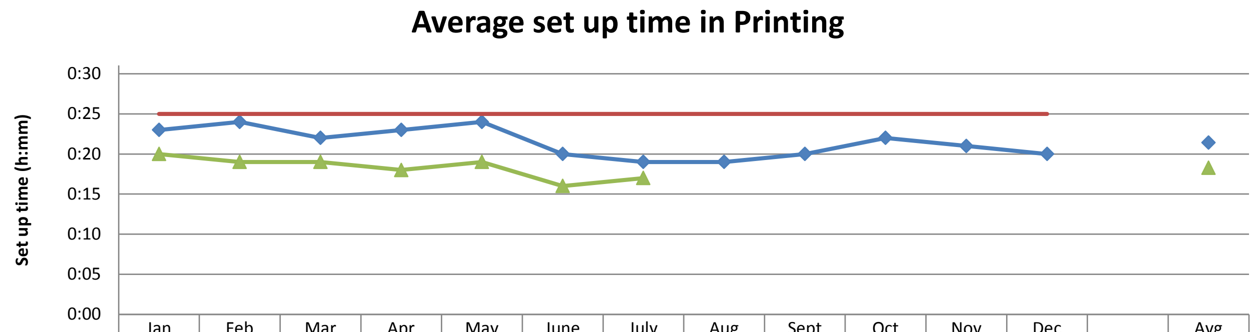
Here, we present the KPIs on the departmental level.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec		Avg
2011	5,657	5,222	5,082	5,984	5,588	6,816	6,057	5,695	6,265	6,702	6,139	5,905		5,973
2012	6,111	5,996	6,848	6,409	6,507	6,224	6,413							6,377
Target	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000	6,000		6,000

Figure 44: KPI average run speed in Printing during pilot.

Figure 44 shows the KPI average run speed, with the results of Printing. We have now precise results during the pilot, but as the pilot was largely in July, we evaluate the results of July. We see no significant difference with earlier result if we look at the result in July.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		Avg
2011	0:23	0:24	0:22	0:23	0:24	0:20	0:19	0:19	0:20	0:22	0:21	0:20		0:21
2012	0:20	0:19	0:19	0:18	0:19	0:16	0:17							0:18
Target	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25	0:25		0:25

Figure 45: KPI average set up time in Printing during pilot.

Figure 45 shows the KPI average set up time in Printing. We see a trend, which seems to have started in October 2011, that the average set up time reduces. The result in July is slightly higher than the previous result, but we dare not say for sure that this is due to the pilot.

5.3.3 Results registration forms

The registration forms serve to give us insight in whether the redesigned MPC process perform as expected. Also, we provide the manufacturing employees and planners with the opportunity to give remarks on the new way of working and report operational issues they encounter. We have of 60% of all shifts in the pilot a filled in registration form.

The planners registered how many changes Printing suggested on their proposed schedule; in 70% of the time, Printing had no suggestions to improve the schedule. This means that, although we are just piloting the redesigned MPC processes, the planners propose in most of the cases a good schedule. If Printing has suggestions, then, on average, they suggest 1 change to the proposal of Planning; for example, to switch 2 combinations.

Recall from Section 5.2.1 that the afternoon shift should be frozen before 12:00 and that the night and morning shifts should be frozen before 18:00. During the pilot, 80% of all schedules were frozen in time. Planning froze some schedules late, because the application in the IS requires an excessive amount of work if a schedule is changed rigorously.

If a schedule is frozen, then manufacturing employees and planners should have registered on the registration form which ad-hoc changes were made to the schedule. From the registration forms follows that, on average, 1 change per shift is made to the schedule. The most common cause for this is that the productivity is higher or lower than expected, then orders are moved between the two printing presses.

5.3.4 Concluding the analysis of the pilot

Now we reviewed all results from the various measurement tools, we conclude the pilot. Our most important observation follows not from our measurement tools, but from the conversations we have had with the manufacturing employees at AVDS. They perceive a much less ad-hoc atmosphere in the manufacturing departments and the planners have significantly more insight in and more grip on the manufacturing process.

In the shop floor data analysis, we see that, although the number of combinations that leave Printing, Die Cut, and Separating late has not decreased, the average lateness of a combination decreased significantly. A combination that is 3.5 hours late interrupts the manufacturing process much less than a combination that is 12 hours late; on top of that, while the former may still be finished in time, the latter is most likely late at the customer. We see the influence of Printing's performance on the consecutive departments Die Cut and Separating clearly. The average set up times are shorter and the average processing times are longer, this is due to the fact that the average combination requires more sheets to be printed (longer run lengths). We also see that the estimation of the set up time in the Printing department is a structural overestimation of the real set up time; currently, all combinations have the same set up time in the IS, while in reality the set up times are long and highly sequence-dependent. The productivity in Printing and its consecutive department, Die Cut increased with about 30% during the pilot, compared to the first quarter of 2012. This is caused by an increased run length and the improved MPC processes. Although the productivity increased, the estimated delivery reliability of AVDS has not improved, but this is due to the (severe) operational issues that Finishing and Boxes encountered during the pilot.

The KPIs that AVDS uses show little improvement. Only the percentage of late deliveries is better than in the same period in 2011, but this has also to do with the fact that AVDS currently has fewer orders than in 2011.

From the registration forms, we conclude that the planners and manufacturing employees followed the plan of the pilot. Printing had in only 30% of all proposed schedules suggestions to improve the schedule; on average they suggested one switch in the schedule. In 80% of the time, Planning froze the schedule in time, and Printing deviated from the schedule once per shift, on average. The latter was mostly due to Printing getting ahead of the schedule. The IS must be adapted to support the new way of planning, because the planners were often hindered severely in making the schedules with the application in the IS.

6. Conclusions and Recommendations

In the previous chapters, Chapters 2, 3, 4, and 5, we answered all four research questions (RQ) we formulated in Chapter 1. Answering the separate research questions, provides us with an answer to the main research question. We conclude this thesis in Section 6.1 and give recommendations in Section 6.2.

6.1 Conclusions

At the start of the project, we established that Planning had no insight in the current status of the manufacturing system and no grip on the schedule. Also, AVDS made significant expenditures on extra (faster) transportation means (€70,000 in 2011) and temporary personnel (€635,500 in 2011), mainly to prevent delayed orders from arriving at the customer too late, which still occurred too often. The main cause of these problems was that the manufacturing departments frequently breached the internal due dates of orders. The root cause of the latter, the so-called core problem, was that AVDS had very fragmented MPC processes. This motivated AVDS to initiate this project.

The main research question concentrated on the core problem and served to guide this project in the right direction. Recall from Chapter 1 that the main research question was as follows.

> *How should the MPC processes at AVDS be redesigned, based on a central planning philosophy, and implemented in order to improve delivery reliability?*

The RQs, derived from the main research question, each focus on another aspect of the main research question. We discussed each RQ in another chapter of this thesis. Recall that the first RQ focused on the current situation at AVDS, the second on the knowledge we need from literature, the third on the actual redesign of the MPC processes, and the fourth on the implementation of that redesign. To develop a redesign of the MPC processes at AVDS, we cooperated with a planning project group, in which we involved the (key) stakeholders of the planning project, gathered their input and feedback, and created support for the implementation that was to come. We discuss the various aspects of this thesis below.

6.1.1 Analysis of the current situation

We started this project with analyzing the current situation at AVDS. We investigated some general characteristics of AVDS: its product range(which has a wide diversity), the external demand pattern (with a strong seasonal pattern), the organizational structure (there is little hierarchy), and the manufacturing process (a general description). Then, we carefully described the current MPC processes and the key performance indicators that were in place. The last and main component of the analysis of the current situation was the shop floor data analysis.

From the shop data analysis, we concluded that the manufacturing departments were very autonomous with respect to planning; we saw that the departments finished many orders late (for example, Printing finished more than 20% of its processed orders late in Q1 of 2012), according to the internal due dates. Even more, the internal due date of an order was not perceived as an internal due date, but more of a guideline. Other observations that followed from the analysis were that the shop floor data was polluted because of the order structure at AVDS, the KPIs focused on operational performance of the departments, and the registration was poor.

6.1.2 Redesign of the MPC processes

In our redesign, we first focused on the order structure at AVDS. This was important to settle first, because of the magnitude of such a change in the manufacturing system and especially in the information system (IS). We elaborately discussed the job (a new type of order). In short, a job is triggered by a customer order and relates to the actual manufacturing process of that customer order; so, basically, a customer order specifies which products a customer ordered and a job specifies how and when to manufacture these products. We discussed how the new order structure looks like with the job included in AVDS's order structure. Then, we explained several modules of the framework that we defined in Chapter 3, namely, the resource loading and job planning (loading jobs to and balancing this load in resource groups), combination-making (making combinations from a set of available jobs), scheduling (sequencing jobs on resources), and the shop floor control module (monitoring the shop floor and responding to disruptions).

For the job planning and resource loading module, we suggested to use a combination due date, which specifies when a combination should be finished at the latest. In combination-making module, we defined the optimal combination and proposed to make combinations on two moments per day (currently once per day). In our discussion on the scheduling module, we explored two extremes in scheduling (central and decentral scheduling), created a hybrid central scheduling process (based on a central scheduling approach, but enhanced with a feedback-loop), explained that AVDS should freeze its schedule before going into effect, and formulated, for every manufacturing department, a set of sequencing rules. In the last module, shop floor control, we created a flowchart on how to adjust a frozen schedule when major schedule deviations occur.

We discussed our redesign repeatedly in the project team and gathered their feedback; in this way, we refined our redesign, created a strong fit between the redesign and AVDS's manufacturing system, and developed support at the members of the project groups. We finalized our redesign with a discussion on KPIs, because the KPIs at AVDS should support the vision of our redesign.

6.1.3 Implementation plan

In constructing the implementation plan, we used the 8-step implementation roadmap of Kotter (1996). This roadmap consists of 8 steps, each tackling frequently made errors in changing organizations; the steps are, respectively, (1) establish a sense of urgency, (2) form a powerful guiding team, (3) create a vision, (4) communicate the vision, (5) empower action, (6) create short-term wins, (7) do not declare victory too soon, and (8) make change stick. We performed the first 4 steps during the course of this graduation project. Currently, AVDS is in step 5; our largest contribution to step 5 was constructing the pilot plan, performing the pilot, and evaluating it. We extensively involved department managers, planners, and manufacturing employees in constructing this pilot plan, partly to incorporate their feedback in the plan and partly to gain their support.

6.1.4 Results of the pilot

The pilot focused on the Printing department; the pilot was effectively an experiment of our redesign. The pilot ran for three weeks, in which we monitored if the involved parties followed the plan. We also kept track of all issues that surfaced and made, together with the manufacturing employees, a list of required changes to the IS; upon his return from his vacation, we involved the manager of the IS in the implementation process to make the required changes in the IS.

At the end of the pilot, we analyzed the performance of the manufacturing departments, to see whether implementing the redesigned MPC processes would improve performance. We used three performance measurement tools, (1) the shop floor data analysis, as we already used in analyzing the current situation, (2) the KPIs that AVDS had in place, and (3) the results of the registration forms, which we developed for use during the pilot.

The results showed that, although the number of combinations that left Printing, Die Cut, and Separating late did not decrease, the average lateness of orders decreased significantly (in Printing, from 12 hours to 3.5 hours). This greatly reduced the severity of a late order. We also saw clearly the influence of Printing's performance on the consecutive departments; an improvement at Printing also resulted in improvements at Die Cut and Separating. The productivity in Printing and Die Cut increased with 30% during the pilot, compared to the first quarter of 2012. Although the shop floor data analysis showed improvements in the performance of the manufacturing departments, the KPIs showed little improvement. Especially the KPIs that report on the external performance of AVDS's entire manufacturing system contained no significant improvements that were caused by the pilot. From the results of the registration forms, we observed that the plan of the pilot was followed fairly accurate and that it was very important that the IS was changed quickly, in order to support the new MPC processes.

6.2 Recommendations

6.2.1 Main recommendations

Because the pilot shows good results, we recommend to continue with the implementation process, which we already initiated, of our redesign of the MPC processes at AVDS. The first obstacle to remove is the fact that the IS is unable to sufficiently support the new MPC processes; we strongly stress to involve the planners in the first place and other manufacturing employees thereafter, in changing the IS. When the IS is ready to support the new MPC processes, we recommend to expand the implementation horizontally to other manufacturing departments.

We further recommend to change the order structure. Incorporating the new order type 'job' into the order structure at AVDS makes it possible to use a unique identifier for every set of physical materials through AVDS's manufacturing system, which largely reduces the pollution of the shop floor data. It also enables traceability, which means that AVDS can determine for every job which resources and materials were used to manufacture it. We suggest that management of AVDS initiates the implementation of this concept in the low season, when the manufacturing system is not as overloaded as in the high season.

Very important though, is that management of AVDS actively steers and monitors the change process. It must create support at every implementation step by involving all the affected employees, and guard against declaring victory too soon: change only sticks when it becomes "the way we do things around here" (Kotter, 1996).

To support the new direction that management of AVDS wishes to take, we suggest that it introduces new KPIs: KPIs that concern the performance related to planning. We suggest two of them: (1) internal delivery reliability and (2) average lateness.

If management of AVDS is able to successfully implement our redesign of their manufacturing planning and control processes, we think that AVDS will reduce its expenditures on extra transportation means and temporary personnel, while at the same time improving its delivery reliability and internal performance.

6.2.2 Miscellaneous recommendations

In this section, we provide AVDS with some miscellaneous recommendations. During the 8 months that we worked at AVDS, we identified issues that are not within the scope of this thesis or for which we did not have time. We discuss these items briefly.

The registration in the manufacturing departments is poor. Especially in the shop floor data analyses, we encountered this issue frequently. We recommend AVDS to investigate how to improve the registration of activities in the manufacturing processes. An option may be to use the concept of Overall Equipment Effectiveness (OEE). For further reading on this topic, we refer to Muchiri and Pintelon (2008) and Williamson (2006).

Currently, AVDS uses a physical order ticket (see Appendix F) which contains information on the order and traverses the manufacturing system together with the set of physical materials of the order. A major disadvantage of this approach is that as soon as the order ticket is printed, it is dated; the link between the IS and the order ticket is broken. We recommend that AVDS moves toward the situation where in the manufacturing departments, all information is retrieved from the IS directly; the physical order ticket is then just the identifier of an order and the carrier of physical reference materials.

When it successfully implemented the redesigned MPC processes, AVDS has a situation where an automated scheduling function may be among the possible extensions. We suggest that AVDS explores this option as soon as management successfully implemented our redesign; automating (a part of) the scheduling module in our framework would, among other things, reduce the amount of repetitive work at Planning.

The IS at AVDS contains a lot of information and provides AVDS with powerful automation tools; however, the user interface of the system is very text-based and applications in the IS tend to contain a large amount of information. We stress that a good user interface is very important in order for employees to master the applications better. We recommend AVDS to develop simpler and more ergonomic applications.

The manufacturing departments Printing, Die Cut, and Separating highly interact with each other. However, from the shop floor data analyses that we performed, we suspect that the capacity in these departments are not in line. We recommend to investigate this observation.

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8. APPENDICES

Appendix A. Detailed manufacturing process at AVDS

Appendix B. Workload planning of Printing and Die Cut

OVERZICHT WERK DRUKKERIJ, LAKKERIJ & STANSERIJ EN WERK DERDEN

	AGIVDS				UITBESTEED			
	Drukken		Stansen		Drukken		Stansen	
	Doorgangen	Druks	Doorgangen	Vellen	Doorgangen	Druks	Doorgangen	Vellen
Totaal gecombineerd	56	190.703	67	189.787	0	0	0	0
	Orders	Vellen						
Totaal niet gecombineerd	17	33.666						

Orderinvoer
16-aug
63
prod. Orders
4
Herstelorders
2

Orderwaarde
16-aug
eenheden
193.587

Dagen zijn van 6.01 uur tot 6.00

VANDAAG

Datum			donderdag 16 augustus 2012	load	vrijdag 17 augustus 2012	load	zaterdag 18 augustus 2012	load	zondag 19 augustus 2012	load	maandag 20 augustus 2012	load	dinsdag 21 augustus 2012	load	woensdag 22 augustus 2012	load
		bezetting														
		ploegen drukkerij	6	prakt. 101%	3,5	prakt. 80%	1	prakt. 91%	2,25	prakt. 90%	2,5	prakt. 131%	3	prakt. 33%	3	prakt. 52%
				theor. 101%		theor. 46%		theor. 15%		theor. 34%		theor. 54%		theor. 16%		theor. 26%
		ploegen stanserij	6	prakt. 72%	3	prakt. 135%	0	prakt. ######	0	prakt. ######	7	prakt. 65%	7	prakt. 49%	7	prakt. 19%
				theor. 48%		theor. 45%		theor. 0%		theor. 0%		theor. 50%		theor. 38%		theor. 15%
		drukuren gepland	38,7		17,9		5,8		12,9		20,9		6,3		10,0	
		stansuren gepland	32,9		30,9		0,0		0,0		34,4		25,9		10,1	
		uren nog beschikbaar drukkerij	-0,4	prakt.	5,7	prakt.	0,7	prakt.	1,8	prakt.	-6,1	prakt.	16,1	prakt.	11,5	prakt.
		uren nog beschikbaar stanserij	13,4	prakt.	-8,5	prakt.	0,0	prakt.	0,0	prakt.	19,8	prakt.	28,7	prakt.	45,4	prakt.
AGIVDS	Drukkerij	doorgangen	36		9	Incl. achterstand	6		10		17		6		8	
		druks	70.346		66.621		8.063		32.565		48.930		10.755		23.769	
	Stanserij	doorgangen	23		20	Incl. achterstand	0		0		19		19		8	
		vellen	57.932		57.862		0		0		71.669		43.721		15.676	
Uitbest.	Drukwerk	doorgangen	0		0		0		0		0		0		0	
		druks	0		0		0		0		0		0		0	
	Stanswerk	doorgangen	0		0		0		0		0		0		0	
		vellen	0		0		0		0		0		0		0	
Orders	Niet gecombineerd of niet meegeteld in load	orders	0		0		0		0		0		3		2	
		vellen	0		0		0		0		0		3.333		1.000	

Datum			donderdag 23 augustus 2012	load	vrijdag 24 augustus 2012	load	zaterdag 25 augustus 2012	load	zondag 26 augustus 2012	load	maandag 27 augustus 2012	load	dinsdag 28 augustus 2012	load	woensdag 29 augustus 2012	load
		bezetting														
		ploegen drukkerij	3	prakt. 0%	1	prakt. 0%	0	prakt. ######	0	prakt. ######	5,5	prakt. 0%	6	prakt. 0%	6	prakt. 0%
				theor. 0%		theor. 0%		theor. 0%		theor. 0%		theor. 0%		theor. 0%		theor. 0%
		ploegen stanserij	7	prakt. 2%	3	prakt. 0%	0	prakt. ######	0	prakt. ######	7	prakt. 0%	7	prakt. 0%	7	prakt. 0%
				theor. 1%		theor. 0%		theor. 0%		theor. 0%		theor. 0%		theor. 0%		theor. 0%
		drukuren gepland	0,0		0,0		0,0		0,0		0,0		0,0		0,0	
		stansuren gepland	0,9		0,0		0,0		0,0		0,0		0,0		0,0	
		uren nog beschikbaar drukkerij	24,0	prakt.	8,0	prakt.	0,0	prakt.	0,0	prakt.	44,0	prakt.	48,0	prakt.	48,0	prakt.
		uren nog beschikbaar stanserij	55,0	prakt.	24,0	prakt.	0,0	prakt.	0,0	prakt.	56,0	prakt.	56,0	prakt.	56,0	prakt.
AGIVDS	Drukkerij	doorgangen	0		0		0		0		0		0		0	
		druks	0		0		0		0		0		0		0	
	Stanserij	doorgangen	1		0		0		0		0		0		0	
		vellen	859		0		0		0		0		0		0	
Uitbest.	Drukwerk	doorgangen	0		0		0		0		0		0		0	
		druks	0		0		0		0		0		0		0	
	Stanswerk	doorgangen	0		0		0		0		0		0		0	
		vellen	0		0		0		0		0		0		0	
Orders	Niet gecombineerd of niet meegeteld in load	orders	8		3		0		0		1		0		0	
		vellen	20.000		8.333		0		0		1.000		0		0	

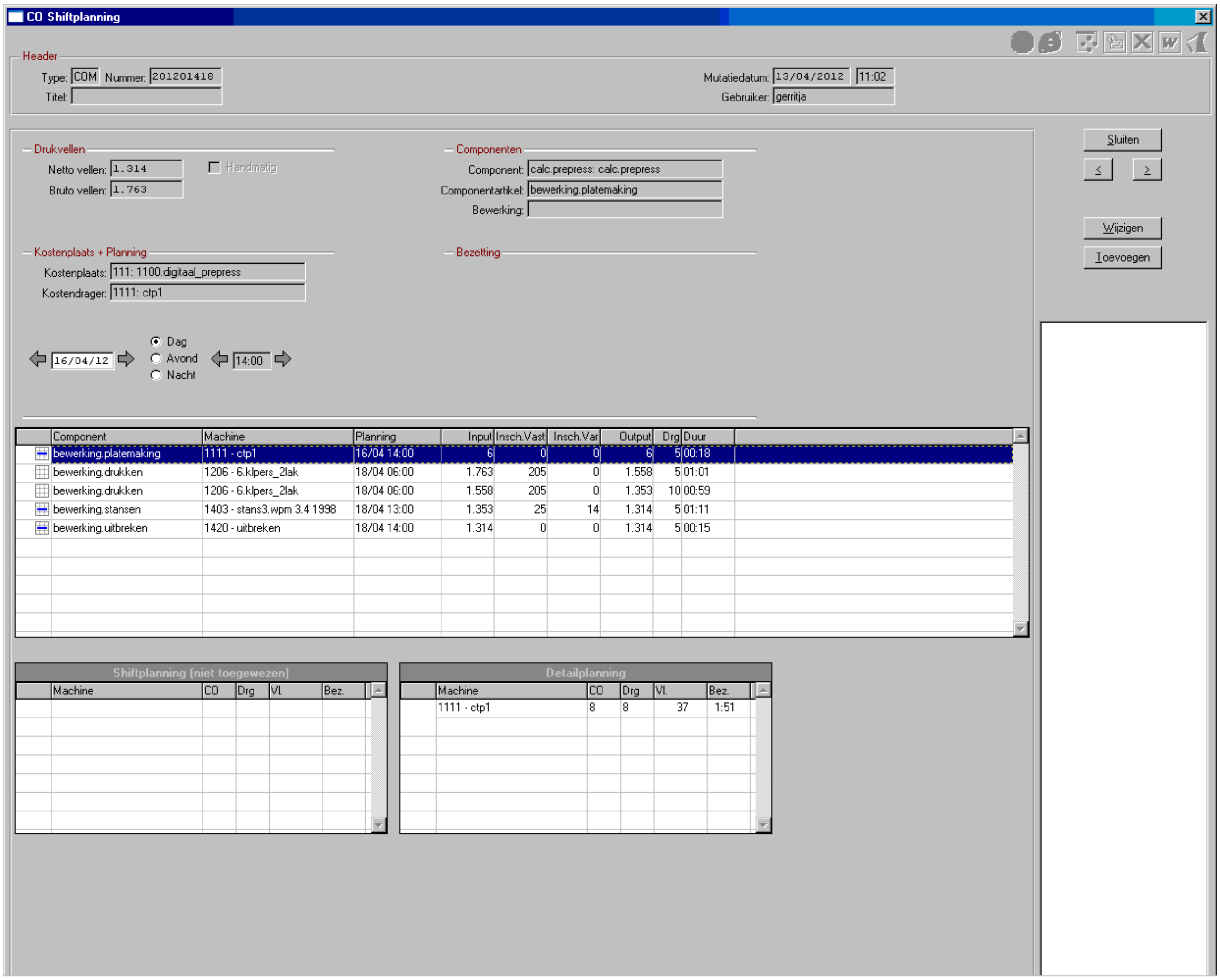
KENGETALLEN		
DRUKKERIJ		
Ploeg	8	uur
Inrichttijd	21	minuten
Wastijd	24	minuten
Benodigde tijd per wissel	45	minuten
Draaisnelheid	6.000	druks / uur
Toegestane tijd opstarten	120	minuten per pers
Toegestane tijd stoppen	180	minuten per pers
Gemiddelde downtime	20,0	%
Maximaal aantal ploegen	6	per etmaal
STANSERIJ		
Ploeg	8	uur
Benodigde tijd per wissel	40	minuten
Draaisnelheid	3300	vel / uur
Gemiddelde downtime	5	%
Maximaal aantal ploegen	9	per etmaal
PREPRESS		
Platen	205	per 2 ploegen
Combi's	34	per 2 ploegen
File check	40	per 2 ploegen

PRODUCTIECIJFERS AFGELOPEN ETMAAL

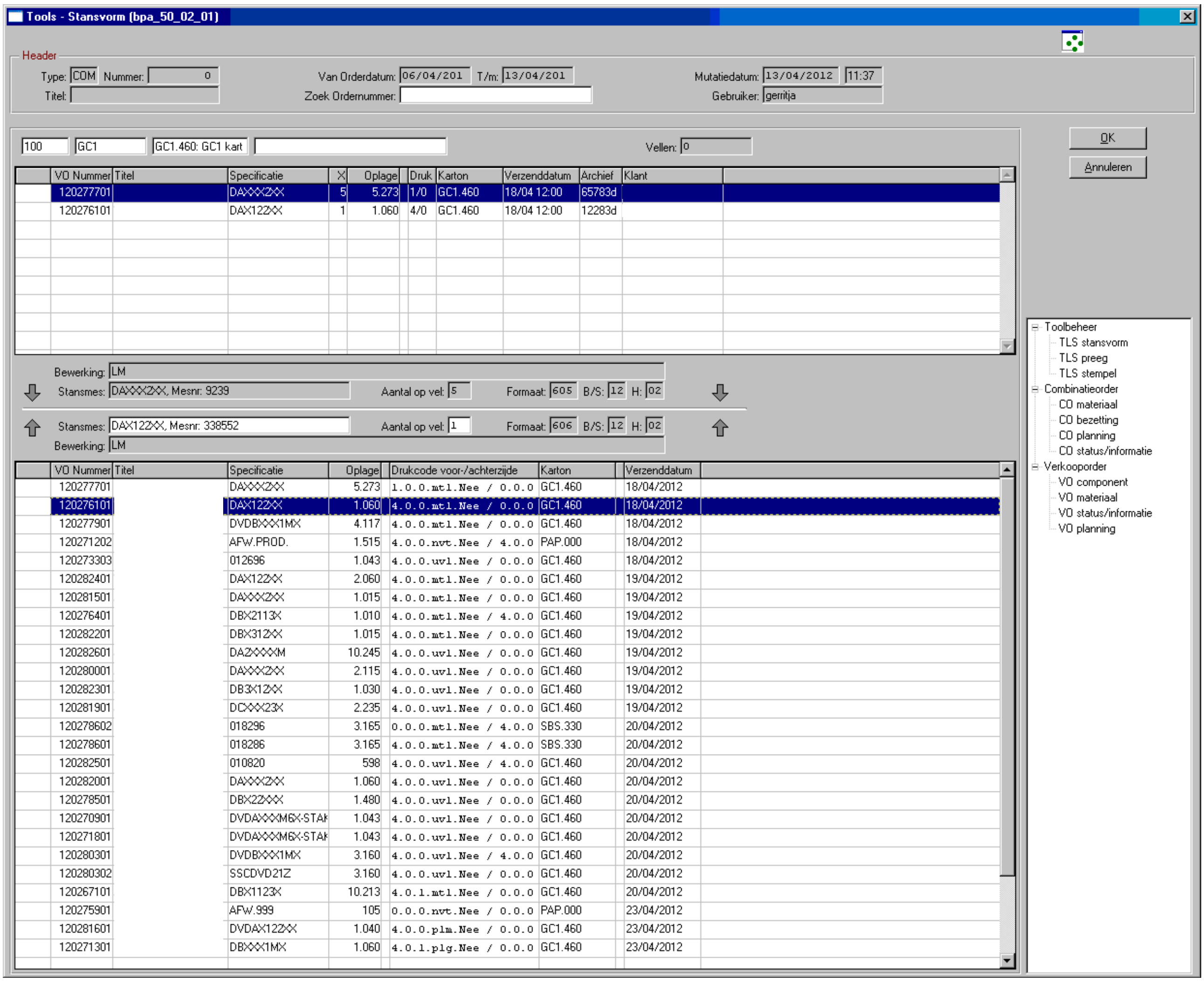
Van: 16-8-2012 06:01 uur
Tot: 17-8-2012 06:00 uur

PREPRESS		Aantal	%
gepland	platen	89	29%
	combi's	21	62%
werkelijk	platen	96	47%
	combi's	23	68%
	files gecheckt	0	0%
	combi's te laat	0	
DRUKKERIJ		**Aantal**	**%**
gepland	doorgangen	40	111%
	druks	76.793	
werkelijk	doorgangen	32	94%
	druks	73.034	
	combi's te laat	1	0
STANSERIJ		**Aantal**	**%**
gepland	doorgangen	25	82%
	vellen	68.467	
werkelijk	doorgangen	19	52%
	vellen	35.995	
	combi's te laat	6	0

Appendix C. Internal due dates of a combination



Appendix D. Creating combinations from multiple orders



Appendix E. Workload in Finishing

Appendix F. Physical order ticket

Van de Steeg Orderbegeleiding **120283101**

Gegevens Algemeen

Debiteurnummer		Site account	AGI van de Steeg	Acc. manager	
Klant		Repeat	Ja	Ingevoerd	teddy
Itemnummer	004228120172990000	Nieuw	Nee	Printdatum	13/04/2012 11:59
Titel					
Productgroep	SDI Digipak	Besteldatum	13/04/2012	Streefaantal	2.010
Productspec.	DB2X13XA	Verzenddatum	19/04/2012	Bestelaantal	2.000
Omschrijving	6 pag digipak 1 tray bkslv mp				
Uitvoering	6 pagina Digipak met 1 tray en een booksleeve voor een 1 mm boekje	Referentie	240-4501241625/10	Modellen intern	10
		Calculatie	prijslijst	Modellen klant	0

Opmerkingen/Bijzonderheden

Specials

uv.lak.glans

Gegevens voorbereiding / Drukkerij

Off kleurproef	nee	Archief	12263d-1		
Aantal kleuren	4 /0 BLACK,CYAAN,MAGENT,YELLOW,				
Aantal PMS	0 /0				
Matlakken	Nee	Vakno	________	Kartonsoort	GC1.460
UV-glanslakken	Ja	Drukformaat	________		
Spot-UV-glanslak	Nee	Materiaal	________	Keurmerk type	Nvt
Lamineren	Nee	Aantal drukvel	________	Keurmerk soort	Nvt
Primer	Nee				

Gegevens Afwerking

RESTDOOS ZO VEEL ALS MOGELIJK AANVULLEN MET GOEDE PRODUCTEN

140.10265 - tray.digipak.cd.crystal 2.010 stuks

Voortgangscontrole

Drukdatum	________	Lakdatum	________	Stansdatum	________	Afwerkdatum	________
Aantal vel	________	Aantal vel	________	Aantal	________	Aantal	________
Paraaf operator	________	Paraaf operator	________	Paraaf operator	________	Paraaf operator	________

Gegevens Werk voor Derden

Gegevens levering / Facturering debiteur **Afleveradres #1** **Afleveradres #2**

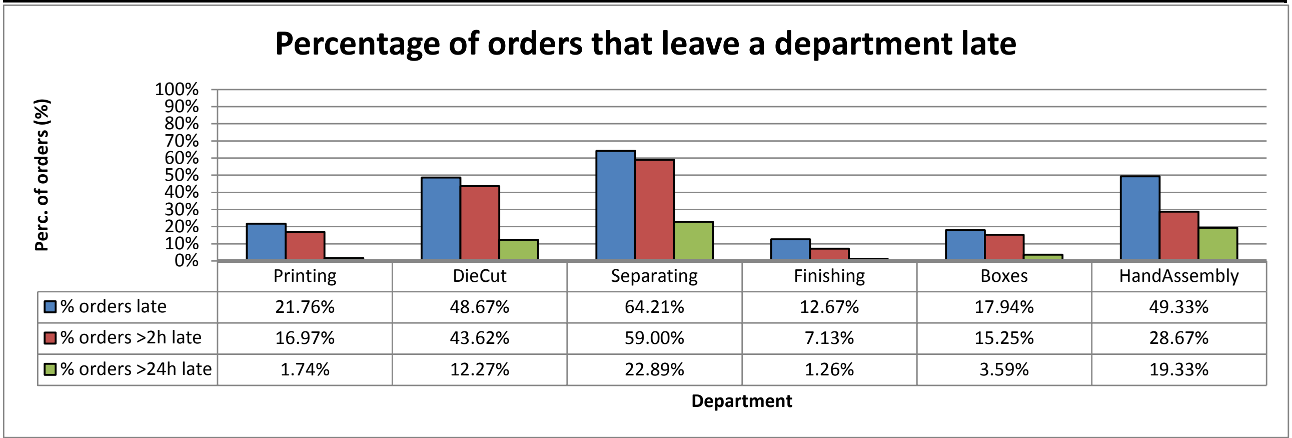
Debiteurcode A / EUR / NVT

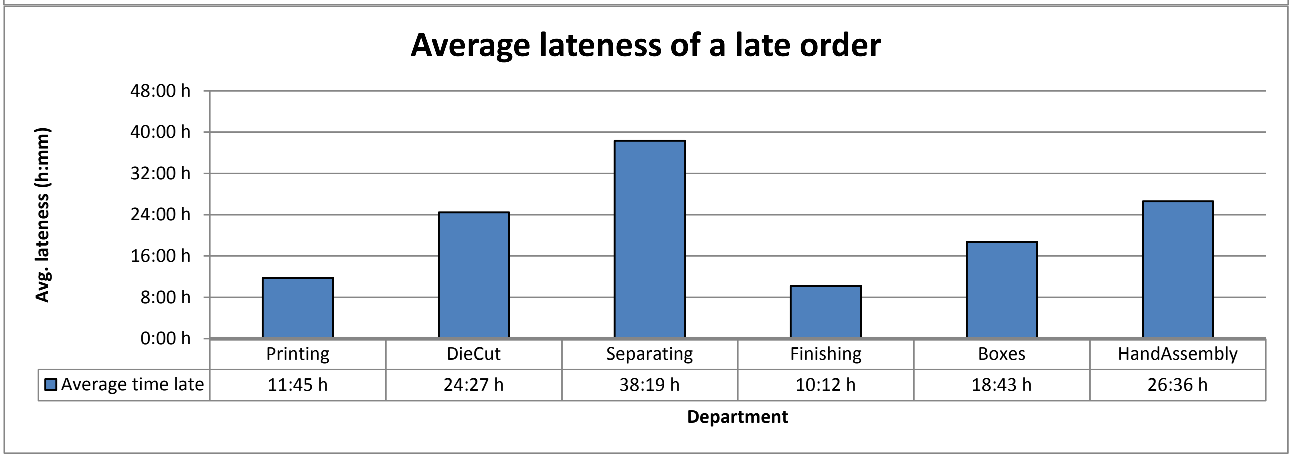
Soort doos: 7a	Aantal: 2.000	Aantal: 10
Aantal per doos: 160	Modellen klant:	Modellen klant:
Gewicht per doos: 9,8	Aantal dozen: à =	Aantal dozen: à =
	Restdoos: à =	Restdoos: à =
Stansmessen:	Totaal uitgeleverd =	Totaal uitgeleverd =
DB2X13XA -LEFT, 391970 - 452/ 13/ 1 (Eff. 13) DB2X13XA -RIGHT, 391970 - 452/ 13/ 1 (Eff. 13)	Aantal pallets : lengte x breedte x hoogte	Aantal pallets : lengte x breedte x hoogte
	Restpallet =	Restpallet =
	Gecombineerd met orders =	Gecombineerd met orders =

Appendix G. Results of the shop floor data analysis (current situation)

LATE_ORDERS

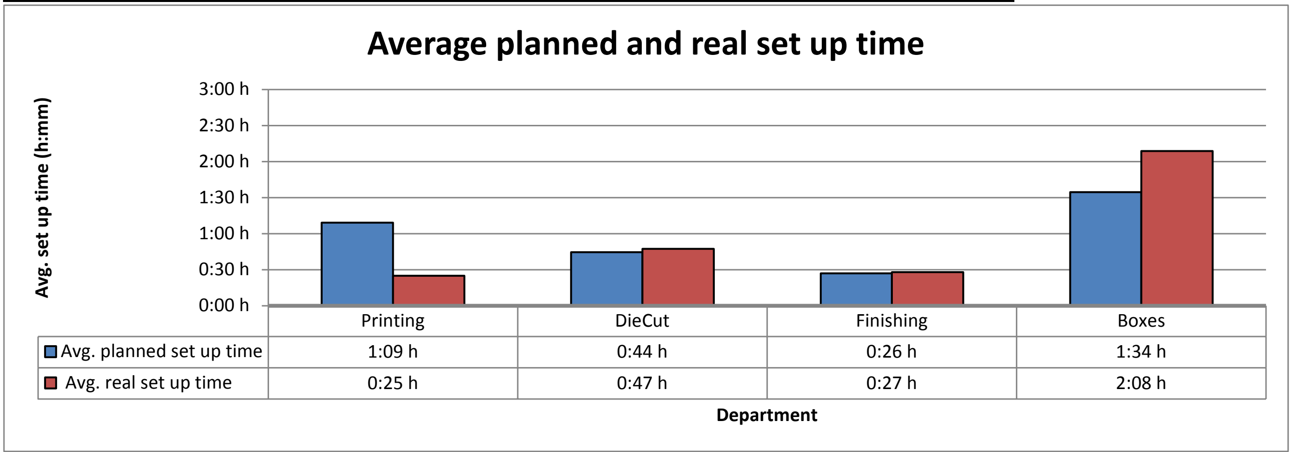
	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
# orders on time	899	619	330	2,081	183	76
# orders late	250	587	592	302	40	74
# orders >2h late	195	526	544	170	34	43
# orders >24h late	20	148	211	30	8	29
Total # of orders	1,149	1,206	922	2,383	223	150
% orders late	21.76%	48.67%	64.21%	12.67%	17.94%	49.33%
% orders >2h late	16.97%	43.62%	59.00%	7.13%	15.25%	28.67%
% orders >24h late	1.74%	12.27%	22.89%	1.26%	3.59%	19.33%
Average time late	11:45 h	24:27 h	38:19 h	10:12 h	18:43 h	26:36 h





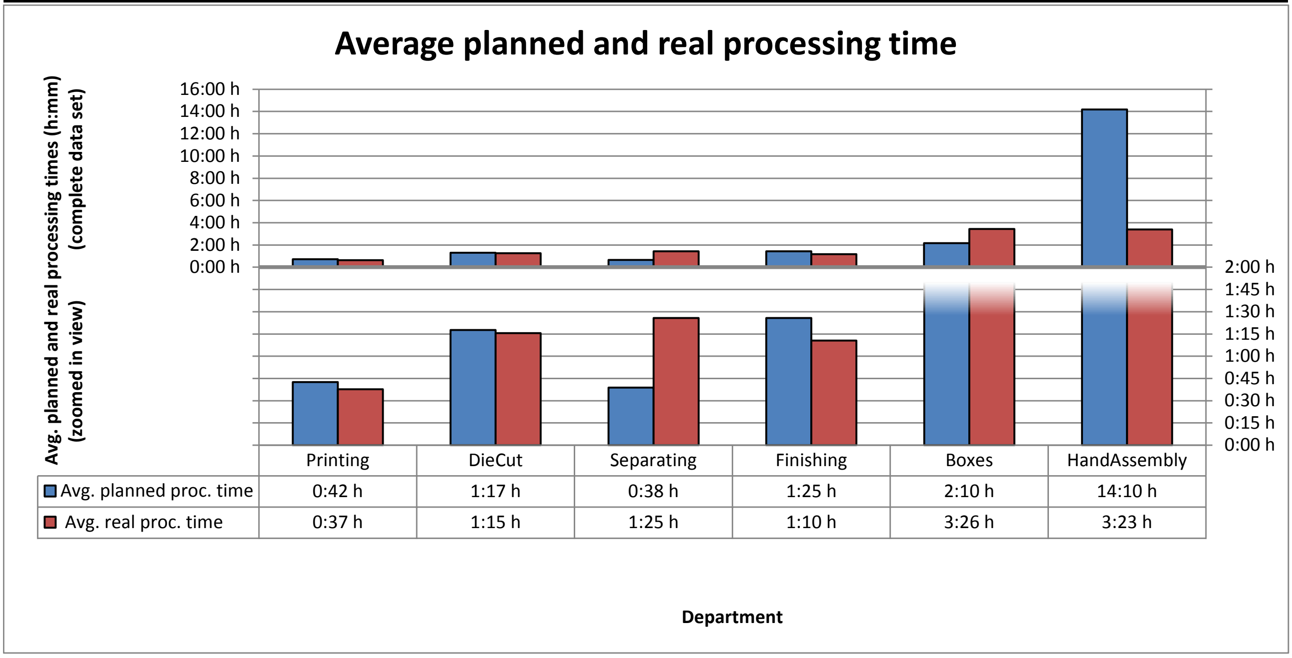
SETUP_TIMES_PLANNING_VS_REAL

	Printing	DieCut	Finishing	Boxes
Avg. planned set up time	1:09 h	0:44 h	0:26 h	1:34 h
Avg. real set up time	0:25 h	0:47 h	0:27 h	2:08 h
Avg. difference	-0:44	+0:02	+0:00	+0:40



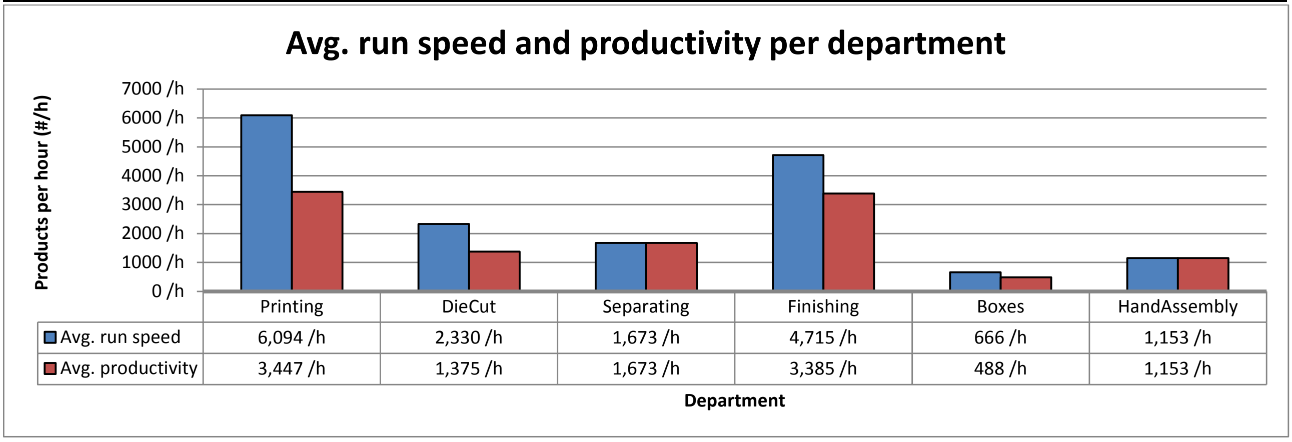
PROCESSING_TIMES_PLANNING_VS_REAL

	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
Avg. planned proc. time	0:26 h	0:49 h	0:27 h	0:53 h	3:02 h	14:02 h
Avg. real proc. time	0:30 h	1:06 h	1:29 h	0:51 h	3:44 h	2:51 h
Avg. difference	+0:04	+0:16	+1:00	-0:02	+0:50	-10:23



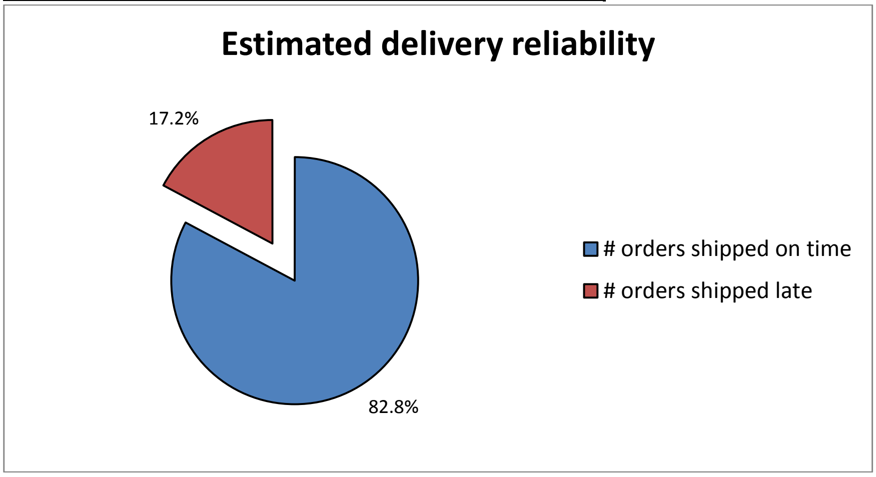
PRODUCTIVITY

	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
Total # products	3,603,928	3,080,344	1,862,080	9,398,348	542,354	416,214
Total run time	591:22 h	1321:48 h	1113:16 h	1993:16 h	814:26 h	360:58 h
Total set up time	454:04 h	919:04 h	N/A	783:00 h	296:58 h	N/A
Avg. run speed	6,094 /h	2,330 /h	1,673 /h	4,715 /h	666 /h	1,153 /h
Avg. productivity	3,447 /h	1,375 /h	1,673 /h	3,385 /h	488 /h	1,153 /h



DELIVERY_RELIABILITY

	AGI VDS
# orders shipped on time	2,472
# orders shipped late	514
Total # orders	2,986
% late	17.21%
Delivery reliability	82.79%



Appendix H. Registration form pilot

Volgnr: 1

Pilot drukkerij - Het nieuwe plannen - Registratieformulier

Ingevuld door:	
Datum:	
Ploeg: *Ochtend, middag of nacht*	

Het planningsproces (het maken van de planning)

1. Heeft Planning de toewijzing en volgorde van de combi's vóór de deadline gedaan? — Ja / Nee * --> tijdstip:
   *Deadline is **11:30** (voor middagploeg) of **17:30** (voor nacht-/ochtendploeg)*

2. Is het voorstel voor detailplanning (door Drukkerij) vóór de deadline gedaan? — Ja / Nee * --> tijdstip:
   *Deadline is **12:00** (voor middagploeg) of **18:00** (voor nacht-/ochtendploeg)*

3. Het bepalen van het voorstel voor de volgorde van combi's nam ... min in beslag: ____ minuten

4. Planning ging akkoord met voorstel na ongeveer ... wijzigingen: ____ wijzigingen

Het wijzigen van de planning (tijdens productie)

Als er toch, nadat de volgorde is bevroren, nog wat veranderd moet worden: ***hier noteren!***

CombiNr	Wijziging in de detailplanning	Tijd	Reden

Opmerkingen / verbetervoorstellen

* = doorhalen wat niet van toepassing is

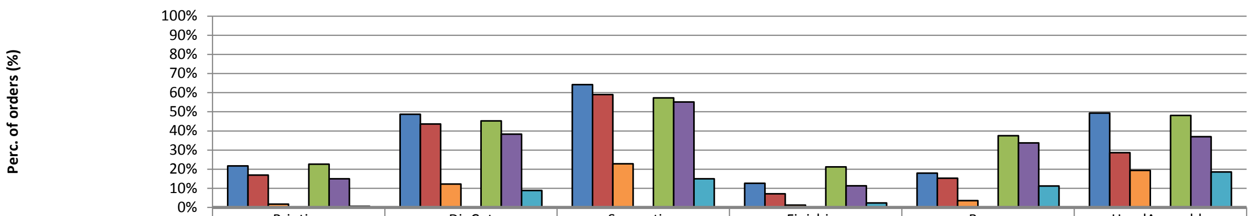
Na afloop van de ploeg dit formulier in het daarvoor bestemde postvakje leggen!!!

Appendix I. Results of the shop floor data analysis (pilot)

LATE_ORDERS

	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
# orders on time	233	160	100	398	50	14
# orders late	68	132	134	107	30	13
# orders >2h late	45	112	129	57	27	10
# orders >24h late	2	26	35	12	9	5
Total # of orders	301	292	234	505	80	27
% orders late	22.59%	45.21%	57.26%	21.19%	37.50%	48.15%
% orders >2h late	14.95%	38.36%	55.13%	11.29%	33.75%	37.04%
% orders >24h late	0.66%	8.90%	14.96%	2.38%	11.25%	18.52%
Average time late	3:28 h	17:06 h	23:13 h	11:25 h	20:12 h	49:41 h

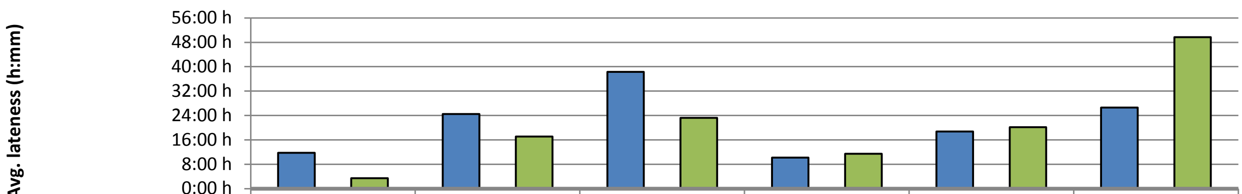
Percentage of orders that leave a department late (Q1 2012 vs. pilot)



	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
% orders late (Q1 '12)	21.76%	48.67%	64.21%	12.67%	17.94%	49.33%
% orders >2h late (Q1 '12)	16.97%	43.62%	59.00%	7.13%	15.25%	28.67%
% orders >24h late (Q1 '12)	1.74%	12.27%	22.89%	1.26%	3.59%	19.33%
% orders late (pilot)	22.59%	45.21%	57.26%	21.19%	37.50%	48.15%
% orders >2h late (pilot)	14.95%	38.36%	55.13%	11.29%	33.75%	37.04%
% orders >24h late (pilot)	0.66%	8.90%	14.96%	2.38%	11.25%	18.52%

Department

Average lateness of a late order (Q1 2012 vs. pilot)

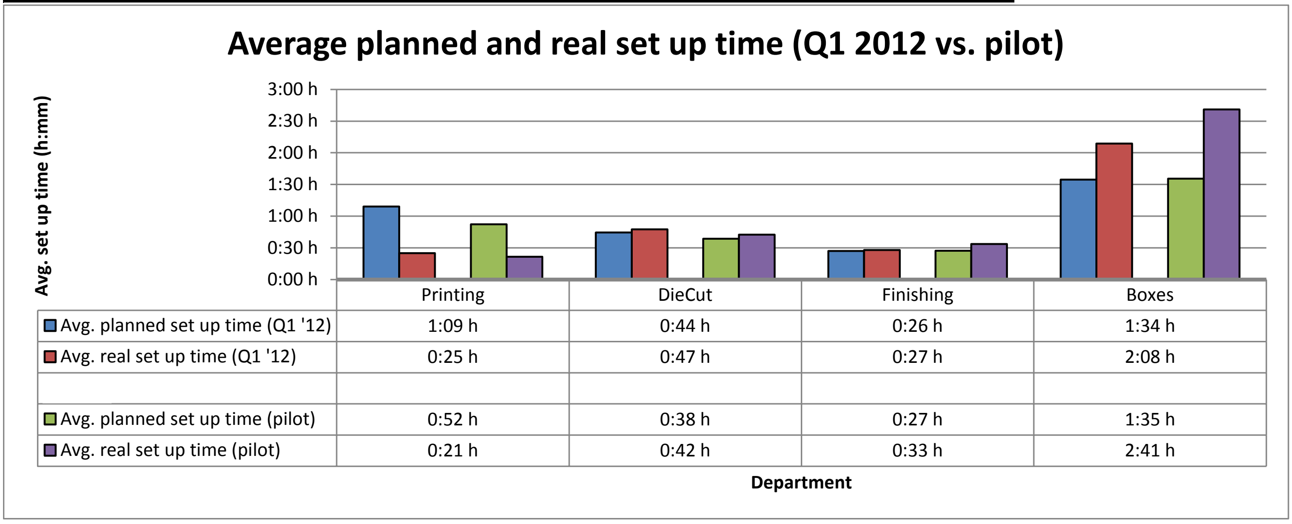


	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
Average time late (Q1 '12)	11:45 h	24:27 h	38:19 h	10:12 h	18:43 h	26:36 h
Average time late (pilot)	3:28 h	17:06 h	23:13 h	11:25 h	20:12 h	49:41 h

Department

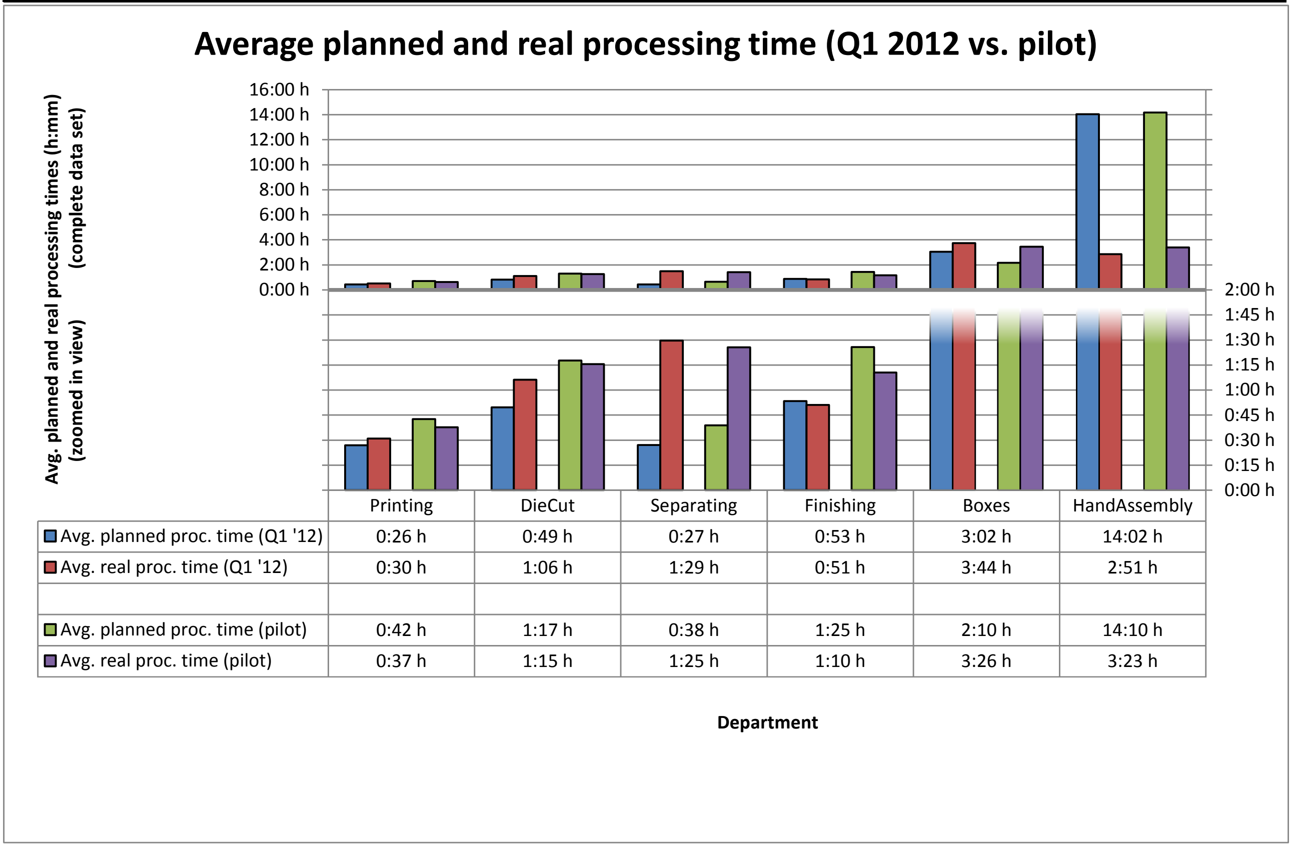
SETUP_TIMES_PLANNING_VS_REAL

	Printing	DieCut	Finishing	Boxes
Avg. planned set up time	0:52 h	0:38 h	0:27 h	1:35 h
Avg. real set up time	0:21 h	0:42 h	0:33 h	2:41 h
Avg. difference	-0:31	+0:03	+0:05	+1:08



PROCESSING_TIMES_PLANNING_VS_REAL

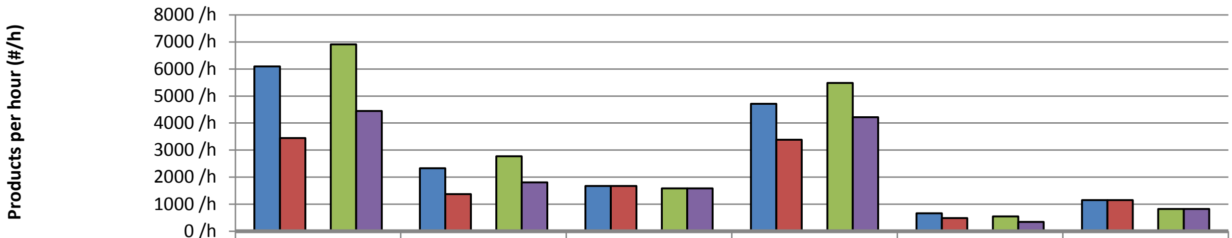
	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
Avg. planned proc. time	0:42 h	1:17 h	0:38 h	1:25 h	2:10 h	14:10 h
Avg. real proc. time	0:37 h	1:15 h	1:25 h	1:10 h	3:26 h	3:23 h
Avg. difference	-0:04	-0:02	+0:44	-0:04	+1:04	-7:41



PRODUCTIVITY

	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
Total # products	1,307,685	1,020,237	726,501	3,200,284	150,153	73,776
Total run time	189:20 h	367:57 h	458:51 h	583:18 h	270:07 h	89:15 h
Total set up time	104:28 h	195:43 h	N/A	175:15 h	163:50 h	N/A
Avg. run speed	6,907 /h	2,773 /h	1,583 /h	5,486 /h	556 /h	827 /h
Avg. productivity	4,451 /h	1,810 /h	1,583 /h	4,219 /h	346 /h	827 /h

Avg. run speed and productivity per department (Q1 2012 vs. pilot)



	Printing	DieCut	Separating	Finishing	Boxes	HandAssembly
Avg. run speed (Q1 '12)	6094 /h	2330 /h	1673 /h	4715 /h	666 /h	1153 /h
Avg. productivity (Q1 '12)	3447 /h	1375 /h	1673 /h	3385 /h	488 /h	1153 /h
Avg. run speed (pilot)	6907 /h	2773 /h	1583 /h	5486 /h	556 /h	827 /h
Avg. productivity (pilot)	4451 /h	1810 /h	1583 /h	4219 /h	346 /h	827 /h

Department

DELIVERY_RELIABILITY

	AGI VDS
# orders shipped on time	502
# orders shipped late	114
Total # orders	616
% late	18.51%
Delivery reliability	81.49%

Estimated delivery reliability (Q1 2012 vs. pilot)