MASTER

Delivery to first manufacturing promise

a study to improve the manufacturing lead time promise determination in a batch process industry

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TU/e technische universiteit eindhoven

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A study to improve the manufacturing lead time promise determination in a batch process industry

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Abstract

This master thesis discusses the lead time promise process of General Electric Plastics. Accurate lead time promise is increasing importance and therefore insight is created in the related sources of variance. Solutions are found in a prediction model and an adjusted lead time promise procedure. First a prediction model is designed to be more accurate in predicting the throughput time of a single order and a set of orders. Second the procedure for lead time promise determination is adjusted in order to deal with the sources of variance, and the future control structure is analyzed on capability of lead time promise.

Preface

In front of you, you find my master thesis. This master thesis is my last chapter of the study Industrial Engineering and Management Science at the faculty of Technology Management of the 'Technische Universiteit Eindhoven' (TU/e). My TU/e adventure started in September 2002. After three years of classes and assignments, I decided to take a job for a while. One year of hard work later, I decided to finish my study. General Electric Plastics gave me the opportunity to do a master research on lead time prediction. This report contains an analysis and redesign for the lead time prediction of General Electric Plastics, soon to become Sabic Innovative Plastics due to company take-over.

Several people contributed to this report, either concerning the content or mentally. Besides all other formal reporting in this thesis, I would like to take this opportunity to thank those people.

In the first place I would like to thank my supervisors, Mr. van Ooijen and Mr. Fransoo from the TU/e and Frank Janssen from General Electric Plastics. Mr. van Ooijen and Mr. Fransoo, challenged me excellent with critical questions, and gave sensible advise on the moment I got stuck. Frank Janssen was a valuable sparring partner, regarding the involved processes at General Electric Plastics. He always managed to stay critical, which kept me focused all the time.

Furthermore I would like to thank my roommate at General Electric Plastics, Bart Jongsma, for the countless discussions about almost every subject possible. I really enjoyed his company. Besides the good company, Bart turned out to be a very good sparring partner, concerning my project.

Then I would like to thank several other people from General Electric Plastics; Jan Bergs and Ruud Havermans, for helping me to gain insight in scheduling; Gerhard Stoeber and Ronald van Zitteren, for the discussions on improving the lead time promise; Almerinda Monte, for sharing her versatile knowledge about the Lexan plant. And of course all the other people that were more or less involved with my research.

Almost last, but mentally the most important, I would like to thank my close friends and family. A special thanks goes to my girlfriend Lisette and my parents. Lisette was by my side when I started in 2002 and supported and motivated me all the way to the end of this adventure. Also my parents were always supporting and very interested.

Finally, I would like to thank Oscar for his everlasting patience and his ability not to ask for attention when there was no time for it.

From now on I will be joining the working class. I expect that the next part of my life will at least be as exciting as the part I leave behind. The writing of this thesis was hard and tough, but I hope that the result is as satisfactory as my research was.

Hugo Kerkhof

Bergen op Zoom, August 2007

Executive Summary

Motivation of the project

In the last decade, conditions in the plastic market have changed, due to the constant increase of total capacity. The vision of General Electric Plastics (GEP) is to focus on the specialty plastics market. Those two elements cause that service is becoming a key competitive advantage. GEP translates service into quality, price and on time delivery. The changed market also causes the need to deliver orders as promised, whereas in the recent past the main focus was on delivery as requested. The fact that customers want an accurate lead time promise is the motivation of this research. It is shown that the current lead time promise accuracy has a high potential for improvement. However, the sources for variance that cause an unreliable lead time for manufacturing are not known.

The project

To be able to improve the lead time promise, first insight is needed in the sources of variance that cause an unreliable lead time for manufacturing. The due date for manufacturing will be named the *manufacturing promise.* Only recently, the focus changed from delivery to request to delivery to promise. So in the recent history, the manufacturing promise was not explicitly determined and no effort was made to commit to the promised delivery date.

First step is to explicitly determine a first manufacturing promise and measure its accuracy. The first manufacturing promise is currently based on the detailed production schedule. Every change in the schedule, after the first manufacturing promise has been generated, is considered as a potential source of variance. By collecting the root causes for the changes, the most important sources for variation are determined. Subsequently it has been investigated how to decrease or eliminate these sources of variance in order to improve the lead time promise accuracy.

One of the root causes for variance is incorrect production planning parameters. It has been shown that the production planning parameters cause a structural imbalance between plan and actual capacity loading. This root cause has been analyzed in more detail, because correct prediction of the workload is necessary for an accurate lead time promise. After all, the capacity loading is one of the key concepts for lead time prediction, regardless of the lead time strategy. Therefore a prediction model has been designed which improves the accuracy of extruder lead time for a single production order, and a set of production orders.

Also the other root causes must be eliminated, decreased or controlled, in order to improve the lead time promise accuracy. It has been analyzed whether it is possible to eliminate or decrease the root causes within the production control structure. By adjusting the lead time promise determination procedure the accuracy can be improved. One of the most important weaknesses of the old procedure was that it did not give every order a margin for variance in the manufacturing process. For the improved procedure, a standard margin is created to absorb the variance, and thus rescheduling.

Main findings

The most important findings of this project are:

1. Optimizing the parameters of the current model for extruder lead time prediction considerably improves its accuracy. However, the manufacturing process is not under control, because the variance in extruder throughput time is too high compared with the mean.

2. The implementation of the new ERP system will solve most of the issues that are caused by lead time prediction based on the current detailed schedule. However, it will not solve the sequence optimization based on changeovers, because it continues to use the current data structure.

3. The adjustment of the lead time promise procedure to give every order a margin of four days for rescheduling considerably increases the lead time promise accuracy. Drawback is that it increases the lead time, because manufacturing is not triggered anymore to produce earlier.

Ad 1: The first finding results from the analysis in chapter 4, where it has been concluded that the current procedure concerning extruder lead time prediction is incorrect. The changeover time depends on the type of changeover. The planned changeover time is not managed and therefore is not in balance with the actual changeover time. The run time depends on the production quantity. However, the prediction model is based on the purchase order, which can be smaller then the minimum production quantity.

To change the behavior of the current prediction model, some parameters can be changed. GEP adjusted the standard run rate, to compensate the imbalance caused by the incorrect planned changeover time and minimum production quantity. However, both imbalances are in reality not related to the run rate. The reason why GEP did use this approach is because there was no insight in the behavior of the current prediction model.

Two improved models have been constructed, one that optimizes the parameters of current model and one that enhanced the model itself. The optimized current model adjusts the parameters for changeover and run time determination. The enhanced model actually adjusts the calculation of the run time, taking into account the minimum production quantity. The enhanced model performed slightly better than the optimized current model. However, both models perform considerably better than the current model. Because the current scheduling software will be replaced in the near future, it has been chosen to implement the optimized current model in order to avoid extra costs. The future scheduling model should however consider the minimum production quantity.

Ad 2: The second finding results from analysis of the new ERP system being implemented in Lexan beginning 2008. Three main issues that are caused by lead time prediction based on the current detailed schedule (PSP) are:

- Lead time promise only given once a day
- Not always the margin target earliness available
- Human intervention needed due to timeslot scheduling

Because the new ERP system will perform lead time prediction based on aggregate information, the lead time can be promised in a split second. Based on the aggregate information it is possible to give every order a fixed target earliness. PS, the successor of PSP, will be flexible in moving around orders, instead of the fixed timeslots. PS can optimize on changeover sequence and due date violation together, by using a penalty system. However the optimization on changeover sequence is based on the current data structure. The result of this changeover optimization is not considered as optimal.

Furthermore the resistance of the plant on due date violation optimization should not be underestimated due to conflicting objectives. The plant is not measured on promised due dates but on an internal due date determined on the moment of order release. A second conflicting objective is that the plant is measured in produced quantity. Optimizing on due date violation will cause a less optimal changeover sequence and therefore lower utilization.

Ad 3: The third finding results from the procedure for determining the lead time promise. Previously some orders did have margin for rescheduling and some did not. The lack of margin is very often one of the root causes for a late delivery. For as long as sources of variation are present, margin is needed to determine a reliable lead time promise. The new procedure makes sure that every order has a fixed margin for rescheduling. However, more margin for rescheduling reduces the need for manufacturing to produce the order earlier. Therefore it is expected that the lead times will increase.

Recommendations

The most important recommendations resulting from this research are:
1. Redefine the data structure for changeover optimization

2. Focus on reduction of changeover time

Ad 1: The current changeover data structure is resulting in a sequence that is considered as non-optimal by the plant. For Lexan this data structure assumes that the color is the determinative factor for the needed cleaning time. However, planners indicate that sometimes additives can be the determinative factor as well. Therefore, the data structure must be more-dimensional. The current data structure has the possibility for two-dimensional changeover determination. However, further research is needed on the desired data structure of the changeovers.

Ad 2: It has been concluded that the variance of changeover time duration is very high compared with the run time. Furthermore the percentage changeover time is very high compared with run time. For more accurate predictability of the lead time, it is important that the changeover time is under control. Therefore it is recommended to reduce the variance in changeover times. On the other hand, reducing the mean of the changeover time will cause higher utilization and therefore more capacity. It is expected that much is to be gained by reduction of the changeover time.

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Part B: Design Phase

1 Introduction

1.1 Company structure

The General Electric Company (GE) is a multinational conglomerate, composed of 6 businesses, of which GE Industrial is one. GE Industrial itself is composed of 8 business units, of which GE Industrial Plastics is one. GE Industrial Plastics (GEP) is a worldwide producer of plastics with production sites and technology centers in 30 locations across 20 countries. The total revenue of GEP in 2006 was 6649 million USD and the net income 674 million USD. At the moment of writing this report, GE Plastics is in the middle of a sale to Sabic, changing its name to Sabic Innovative Plastics. To prevent confusions, only the name GE Plastics will be used in this report.

The project takes place at the production site of GEP in Bergen op Zoom. The organizational chart (figure 1-1) shows that the organization of the production site is split–up into 6 departments. The project takes place within the compounding department. The compounding department exists of three compounding plants: Lexan® Finishing (LXF), Noryl® (NOR) and Flexible Compounding Plant (FCP). Furthermore the compounding department consists of three support departments that support the compounding plants. Fulfillment is one of the compounding support departments and the initiator of this thesis project. Fulfillment is responsible for growth within the plants in the large sense of the word. This means satisfying customer needs from compounding perspective, like product quality and short lead times for existing and new products.

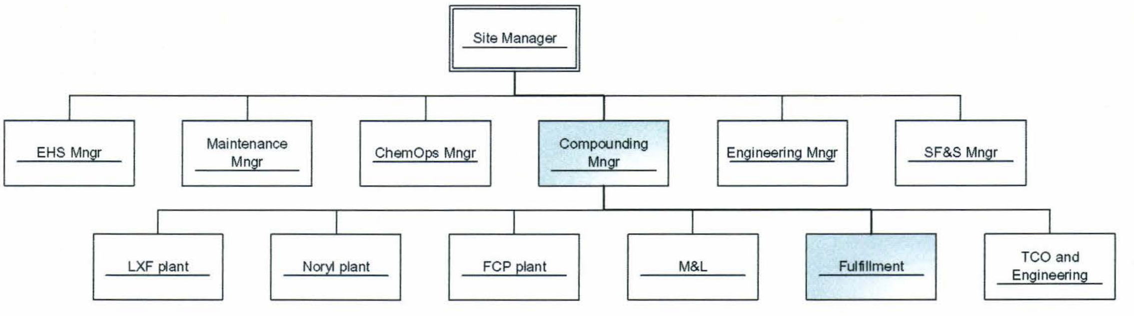

Figure 1-1: Organizational chart

1.2 Product

In Bergen op Zoom, plastic pellets[1] are produced from raw materials. Customers, like for instance molders, use these plastic pellets to create a vast diversity of plastic applications. Therefore plastic pellets can have different specifications, which are a combination of different grades of resins, additives and color pigments. In 2006 the Bergen op Zoom compounding produced 207 kilotons of pellets, consisting of 3745 different products. These 3745 are created out of 675 grades and 2136 colors. Finally every product can be packaged into several package sizes.

GEP is able to create different types of plastic in virtually every color, what means there are virtually unlimited different products. Distinction between colors is very important for production control, because of sequence dependency.

[1] A plastic pellet is a small chunk of plastic approximately with an diameter of a couple of milimeters

1.3 Demand

There are two types of markets for plastics:

- Bulk market, characterized by high volumes and low margins.
- Specialty market, characterized by low volumes and high margins.

To differentiate among competitors, GEP focuses on the specialty market. Because of its production characteristics GEP is producing in batches. The focus on the specialty market will increase this need, because of lower order sizes.

GEP has divided its products in Make To Order (MTO) and Make To Inventory (MTI)[2]. Once every two months it is reviewed whether a product is MTO or MTI, using a standard procedure [appendix A]. Per year, the proportion of total quantity in tons MTO versus MTI is approximately 1 to 1, so both are sold almost equal.

For the MTI-items the demand is relatively stable and predictable. In contrast, the demand for MTO items can be described by the characteristics of a typical batch process industry. Ivanescu (2004) gives three characteristics of the demand in this type of industry: low demand volume per product, small number of customers per product and high variability and dynamics of demand. It is therefore difficult to provide accurate and reliable demand forecasts for the MTO-items.

The demand volumes show a strong increase at the end of every quarter, also referred to as the 'hockey stick pattern'. This pattern is not a result of unstable demand, but a result of the internal processes. Because the sales department is quarterly evaluated on production volumes, the sales increase at the end of every quarter as a result of given discounts to reach the sales targets. As the production capacity is constant in the medium term, this hockey stick pattern is counteracted by "stock building" of MTI products at the beginning of the quarter, called level loading.

1.4 Manufacturing process

The manufacturing process of GEP is given in figure 1-2. In Chemical Operations plastic powder with specific properties is produced. This powder is used in compounding, together with some raw materials to create the finished goods. The customer order decoupling point for MTI products is at the finished goods. The customer order decoupling point for MTO products is at the powder storage.

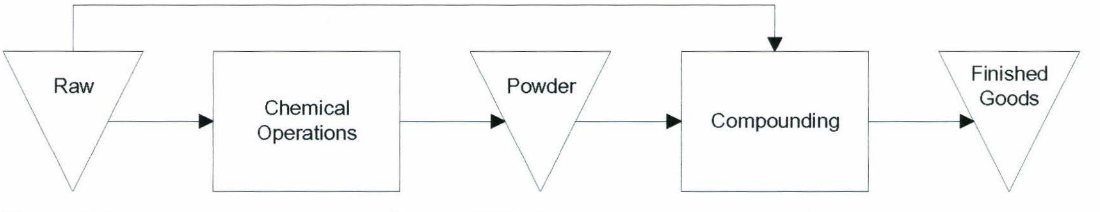

Figure 1-2: Manufacturing process diagram GEP Bergen op Zoom high level

This research will focus on Compounding, therefore the manufacturing process diagram for compounding is given in figure 1-3. This process consists of blending, extrusion and packaging.

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[2] In the literature this is generally known as Make To Stock (MTS). The abbreviation MTI is typical for GEP, and will be used in this report

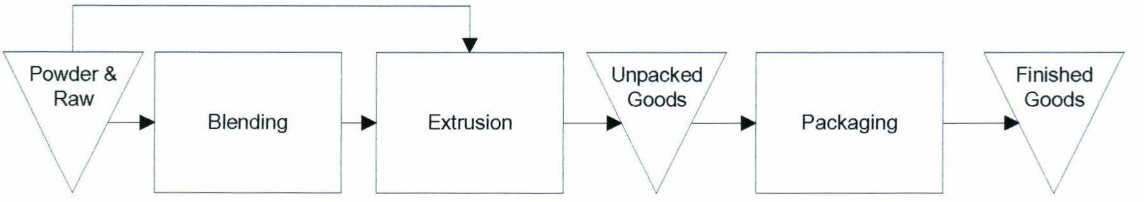

Figure 1-3: Manufacturing process diagram Compounding

In the blending process, the powder from Chemical Operations together with several raw materials is fed into a blender. The blenders have a maximum capacity and a minimum blending time. After blending, the blend is fed into a silo called surge bin, from where the correct quantity is dosed to the extrusion line via a loss and weight feeder.

In extrusion, the blend from the surge bin is fed into the extruder. Also some powder and raw materials are fed directly into the extruder, without using the blender. This can be seen as mixing syrup, where the blend is the syrup and the other raw materials are the water.

All the materials are heated up in the extruder via friction created by the extrusion screw. This friction, transforms the materials into a liquid substance. This liquid substance is then pushed through a mould with small holes, creating plastic strands. After water-cooling, the strands are chopped into pellets by a pelletizer. The pellets are screened by a sieve for correct measurements, and then collected in a product bin, which contains the unpacked goods.

After collecting the products in the product bin, the products are ready for packaging. The pellets are packaged into containers, like bags, carton octabins or bulk trucks. After packaging, the goods are ready to be shipped to the warehouse finished goods, but between extrusion and transfer to finish goods a quality check has to be performed. Until the quality is assured, the goods will be kept in the plant.

1.5 Business Case

Because of the focus on the specialty market, service has become a top competitive priority in GEP's manufacturing strategy. GEP translates service into three aspects: price, quality and on time delivery. The request for this project is to improve the last service aspect, on time delivery. On time delivery is defined as delivery of the promised volume on the promised date. The process behind on time delivery is the order to delivery (OTD) process. OTD is defined as the process from order entry to delivery at the customer, with respect to time.

To know the voice of the customer, GEP is using a so-called NPS survey. NPS stands for Net Promoter Score, which is a continuous survey. The main question of the survey is how willing the customer is to promote GEP to relatives. A partial result of this survey is involved with promised delivery dates. The date that the customer initially requests an order to be delivered is called the requested delivery date (RDD). The date that GEP promises to deliver the order is called the confirmation date in GEP terminology. To stay in line with the literature, the name promised will be used instead of confirmed.

The results of the NPS survey show that customers indicate an opportunity for improvement in delivery to promise. Two opportunities are indicated. The first opportunity is that GEP does currently not deliver as promised initially. The second opportunity is the number of adjustments in promised dates. Both opportunities are related to the accuracy of the initial promise, so there is an indication that GEP is not able to determine a sufficient accurate lead time in advance.

1.6 Report structure

In chapter 2, the problem statement will be presented, based on a survey. Then, GEP fundamentals are presented. These fundamentals are important for the argumentation of the performed analyses. Subsequently, the problem is analyzed and quantified and finally the impact of Manufacturing is determined.

In chapter 3, the delivery to manufacturing promise is analyzed. First it is investigated which part of the process is the main originator for incorrect delivery to manufacturing promise. Then, insight will be created in the part of the process for which currently no insight is available. At the end of this chapter, the final assignment will be constructed, concerning the design phase of the project.

In chapter 4 a model is presented to improve the prediction of the extruder lead time. Then in chapter 5 the lead time promise is analyzed and improved. Finally the report ends in chapter 6 with conclusions and recommendations.

2 Problem Analysis

The motivation of the initial assignment is based on a customer survey. Therefore, this chapter starts with the results of that customer survey (2.1). After that the initial assignment will be introduced (2.2). Then, some GEP fundamentals will be introduced, which is needed to understand the remainder of this thesis (2.3). Thereafter, the problem will be quantified (2.4). Subsequently, the relation between the problem and manufacturing will be quantified, because the focus of research will be on manufacturing (2.5). This chapter ends with a discussion of conclusions.

After reading this chapter it will be clear why there is a need for improving the on time delivery from a manufacturing perspective. Continuing on that, chapter 3 will describe where this improvement is to be expected.

2.1 NPS Customer Survey

To know the voice of the customer, GEP is using a so-called NPS survey. NPS stands for Net Promoter Score, which is a continuous survey. The main goal of the survey is to gain insight in how willing the customer is to promote GEP. A partial result of this survey is related to service and on time delivery. For more detailed explanation of the NPS Survey is given in appendix B. In this section, results from this NPS survey will be presented, concerning delivery.

Every month 40 to 60 customers submit the NPS survey on Support after Sales, Delivery, Innovation, Quality and Ease of doing Business. Figure 2-1 shows the scores on Delivery on the left side compared to the best performer, being Quality, on the right side. Delivery has a score of approximately 0% for the last half-year. Compared to the other four subcategories, Delivery has an opportunity to improve. For instance, Quality has an average score of above 40% for the same half year. It can be concluded that customers are more satisfied with Quality then they are with Delivery performance, indicating that there is an opportunity to improve the Delivery performance.

Figure 2-1: NPS score for Delivery and Quality

A dataset of 94 GEP-customer surveys is used to found the statement of the initial assignment. Results are shown in figure 2-2. In total 36 times a useful explanation was given on the specific questions. From these 36 useful explanations, 20 were giving the message that there were too many late deliveries and too many reconfirmations. Furthermore 10 explanations were due to bad communication on confirmations and only 1 customer complaint was made about too long lead times. The remaining 5 explanations were positive feedback. This strengthens the call for the higher priority focus on accurate lead time promise before reducing the lead time.

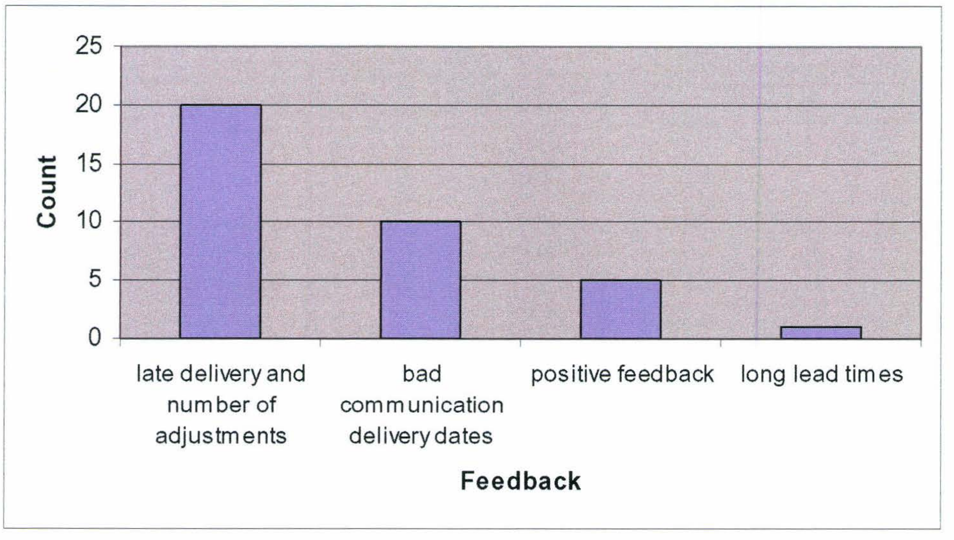

Figure 2-2: Feedback of customers on Delivery performance

Within the survey, remarks are identified on the topics of the number of late deliveries and number of changes in promised delivery date:

- "late deliveries, almost every delivery was delayed"
- "90% of the time a few days late"
- "Some competitors perform much better"
- "Changes of the delivery date are happening often"
- "Direct shipments get too often reconfirmations, while they need to be first time right".

General trend shows that customers want reliable and accurate promised delivery dates. Conclusion from the surveys is that the customer considers two major opportunities for improving on time delivery:

1. GEP's performance of delivery to first promise needs improvement
2. GEP should minimize its number of adjustments in the promise delivery date

The second point, minimizing the number of adjustments in the promised delivery date, is a direct result of the delivery to first promise, but also includes the message that once a promise is given, it should not be changed several times. So when it is necessary to change the first promise, the new promise should be considered as the target and not trying to deliver on the old promise.

2.2 Initial Assignment

Because of the focus on the specialty market, service has become a top competitive priority in GEP's manufacturing strategy. GEP translates service into three aspects: price, quality and on time delivery. The request for this project is to improve the last service aspect, on time delivery. On time delivery is delivery of the promised volume on the promised date. The capability of on time delivery is measured by order to delivery (OTD), what can be defined as the process from order entry to delivery to the customer, with respect to time.

As shown in the previous section, it can be concluded that GEP has an opportunity to improve the delivery to promise. This opportunity is two fold. On the one hand, customers indicate that GEP's performance on delivery to first promise can be improved. On the other hand, customers indicate that GEP should minimize the number of changes in the promised delivery date.

The customer surveys indicate that customers give higher priority to delivery to first promise than they do to delivery to request. In the past, GEP has been focusing on delivery to request, instead of delivery to first promise. To comply with the customer need, GEP will have a first priority of delivery to first promise and a second priority on short lead times, or in other words, delivery to request.

Problem Statement: Currently GEP is not sufficient capable to deliver to first promise, while customers indicate that delivery to first promise has high priority.

There is very little insight in what the drivers are for the low delivery reliability, because until recently the only focus was on delivery to request. Now service is increasing in importance, the focus is shifted towards delivery to first promise, with as goal high delivery reliability. After high delivery reliability is achieved, the next important goal is to shorten the delivery lead-time.

The physical order to delivery process can be separated into two parts. The first part is manufacturing, in which the products are produced. The second part is the distribution, in which the products are kept on stock and distributed to the customer. Both parts are clearly separated and therefore it is possible to distinct the research to one of those. This assignment will initially focus on the manufacturing, because this is where the research takes place.

From a manufacturing perspective there is only one internal customer, which is the Supply Chain Management Department. Manufacturing should produce the products on time so that Supply Chain Management has enough time to distribute the goods to the customer, regarding a standard lead-time to that customer. Therefore, internal delivery dates are derived from the customer delivery date to make sure enough time is available for distribution. Furthermore insight must be created into the relation between manufacturing and promised delivery dates

The **initial assignment** is to conduct research on how to improve both the first promised date and the communication rules to the customer from a manufacturing perspective.

2.3 GEP Fundamentals

Before analyzing and quantifying the problems mentioned in the previous section, some fundamentals are introduced. The analysis and quantification will be based on these fundamentals.

The first fundamental is the difference between a Sales Order (SO) and a Purchase Order (SO). The SO is the customer order. The PO is an internal order for production, placed at manufacturing.

The second fundamental is the customer order decoupling point. GEP differentiates its products as Make To Inventory (MTI) and Make To Order (MTO). In standard literature MTI is named Make To Stock (MTS). However, to stay in line with GEP terminology the term MTI will be used throughout this report. The customer order decoupling point for MTI products is at the logistic warehouse. The upper part of figure 2-3 shows that there is no direct link between the SO and the PO, because the PO is a stock replenishment.

MTO products are only produced when a customer order is placed. The customer order decoupling point for MTO products is between Chemical Operations and Compounding. The lower part of figure 2-3 shows that a link exists between the SO and PO of MTO products.

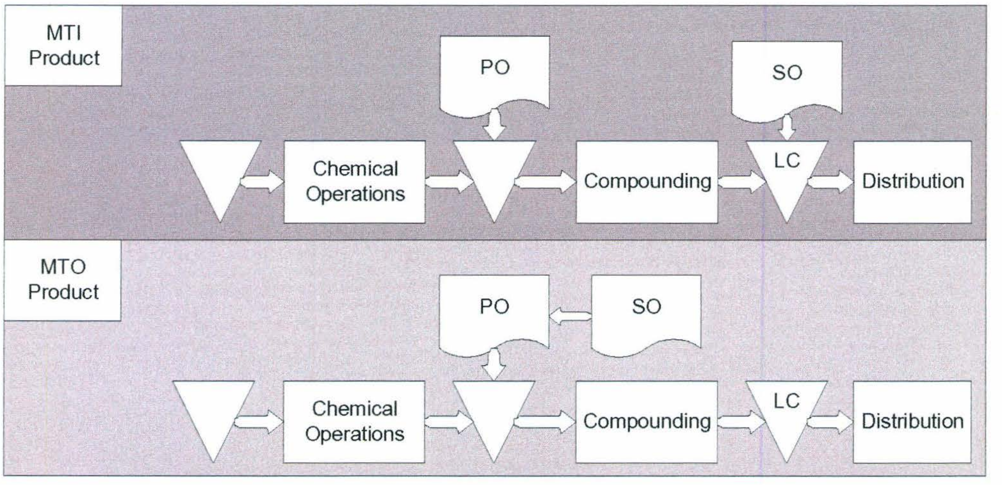

Figure 2-3: Order flow separated as MTI and MTO products

The third and last fundamental is the lead time promise cycle. For MTI products, the lead time promise is generally based on the distribution lead time, because the products are on stock. The distribution lead time consists of transportation time and one day warehouse handling.

For MTO products, the lead time promise is based on the manufacturing and distribution lead time. The manufacturing lead time is based on a detailed production schedule. The customer places a SO with a requested delivery date. After the corresponding PO has been scheduled on the detailed schedule, the lead time promise can be generated.

Customers indicate that the promised delivery date is often adjusted (2.1). This is a result of the promise adjustment logic, which can be found in appendix I. Due to this logic, an adjustment in the detailed schedule can originate an adjustment in promised delivery date. Finally, when the PO is finished, the products are ready for shipment and the distribution lead time starts. The lead time promise generation and adjustments is named the lead time promise cycle. A more comprehensive description of the lead time promise cycle is presented in appendix C.

2.4 Problem quantification

From the NPS survey it is concluded that GEP has two major opportunities for improving delivery performance (2.1);

1. GEP's performance to deliver to first promise needs improvement
2. GEP should minimize its number of adjustments in the promise delivery date

The two subjects will be quantified based on a historical dataset of the last half-year of 2006. In this section the performance is quantified on overall business impact. The next two subsections will discuss the two subjects on overall business performance.

2.4.1 Delivery to first promise performance

To determine if the delivery to first promise indeed needs improvement, the current performance will be analyzed. For that purpose a dataset of all SO's shipped from the Bergen op Zoom warehouse in Quarter 3 and 4 of 2006 is analyzed.

The First Promised Delivery Date (1[st]PDD) is compared with the Actual Delivery Date (ADD). This comparison is defined as;

ADD < 1[st]PDD : Early

ADD = 1[st]PDD : On Time

ADD > 1[st]PDD : Late

Figure 2-4 shows the results of this grouping analysis. The most right bar shows the grand total performance for the analyzed period. It can be concluded that the average performance of delivery to promise was 35% late, 40% on time and 25% early. Therefore the conclusion is that delivery to first promise indeed needs improvement.

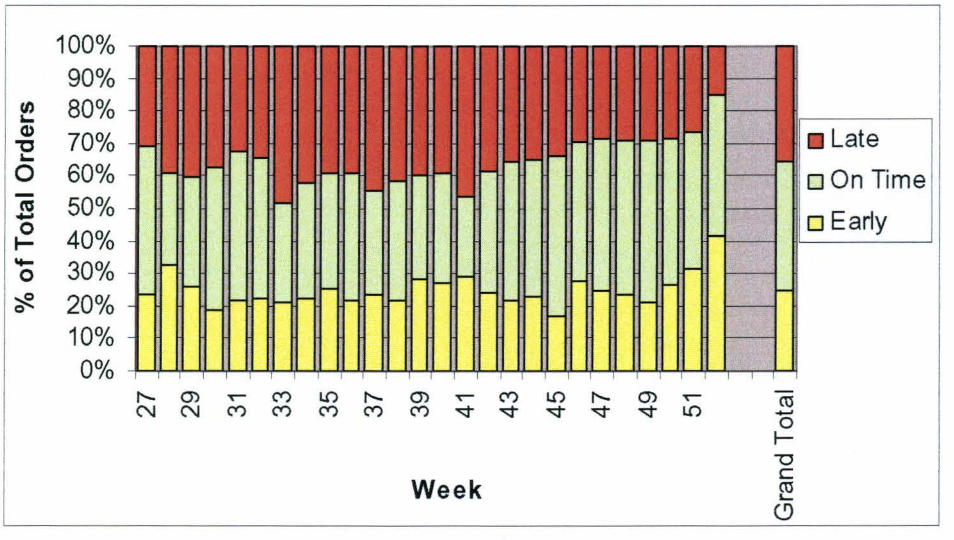

Figure 2-4: Delivery to first promise performance (Data: SO, Bergen op Zoom, Q3-Q4 2006)

Another aspect of the analysis is to determine how many days GEP is delivering late versus 1[st]PDD. In figure 2-5 the result of this analysis is shown. This analysis is based on the same dataset. The total number of analyzed SO's is 14940. Figure 2-5 shows a histogram of the late SO's. Approximately 50% of the late SO's are delivered more then 3 days later than the 1[st]PDD. The average lateness is equal to 5.7 days with a standard deviation of 7.1 days. So also here it must be concluded that delivery to first promise needs improvement.

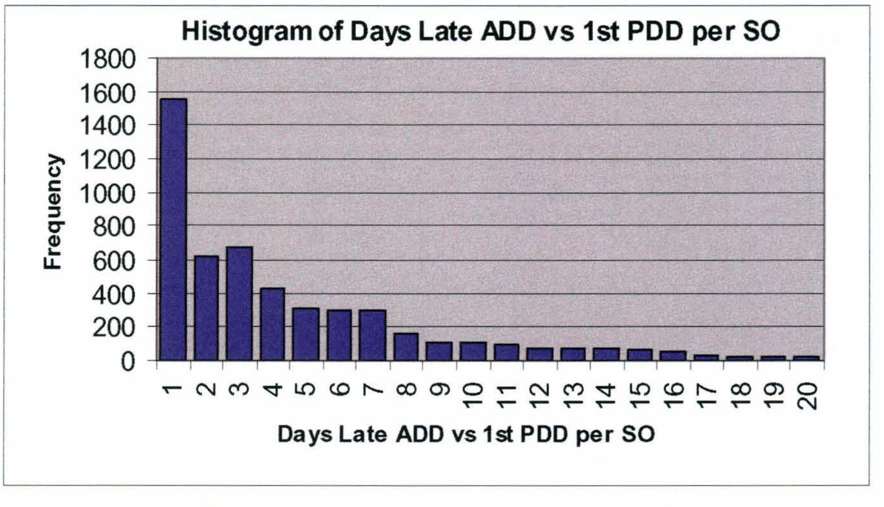

Figure 2-5: Histogram of number of days late delivery based on 1st Promised Delivery Date (Data: SO, Bergen op Zoom, Q3-Q4 2006)

2.4.2 Adjustments in Promised Delivery Dates

It was concluded that adjustments are a result of the promise adjustment logic (2.3). To determine whether the number of adjustments in the Promised Delivery Date (PDD) is too high, the current number of adjustments is analyzed. GEP is already measuring the number of adjustments.

The result of this measurement is presented in a histogram in figure 2-6. Approximately 41% of the SO's do not get an adjusted PDD, 21% gets one adjusted PDD and the PDD is adjusted twice or more for 38% of the SO's. On average every SO gets 2.0 adjustments with a standard deviation of 2.0 adjustments. The histogram, shown in figure 2-6 indicates that the number of adjustments is not normal distributed, but has a heavy tail, indicating a possible exponential distribution.

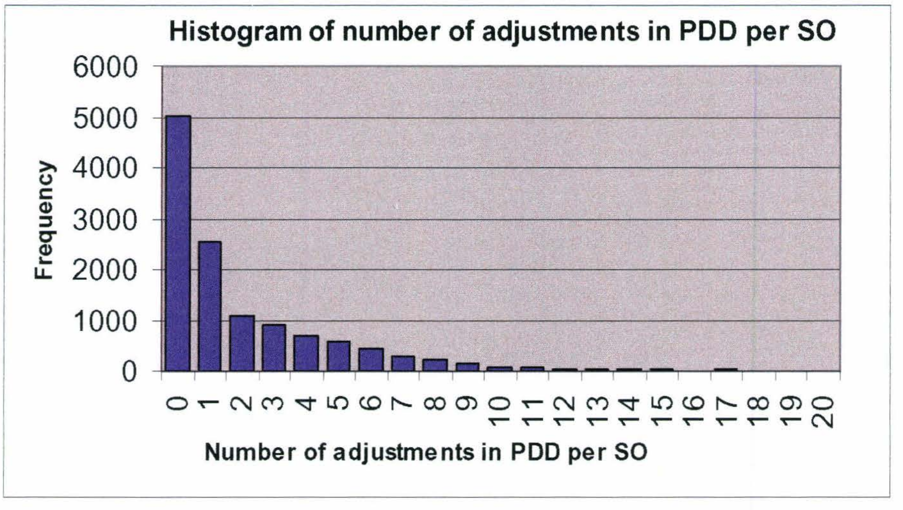

Figure 2-6: Histogram of number of adjustments in PDD per SO (Data: SO, Bergen op Zoom, Q3-Q4 2006)

From figure 2-6 can be concluded that there are indeed many adjustments in PDD. GEP already started a project to reduce the number of adjustments communicated to the customer. Only the expected week of delivery is formally communicated. However, the customer can still find the exact promised delivery date on the Internet. Therefore, every adjusted PDD is considered as undesirable.

2.5 Manufacturing problem quantification

In the previous section it has been concluded that delivery to promise indeed needs improvement (2.4.1) and the PDD is adjusted too often (2.4.2). This section investigates whether both subjects are related to Manufacturing. It is expected that Manufacturing causes a large number of adjustments, in example due to execution delay. To prevent confusion about the scope, first Manufacturing is defined.

Definition: **Manufacturing** is defined as all activities needed that are related to a PO, from order entry until finished product.

It has been concluded that no direct link is available between the SO and PO for MTI products (2.3). A first promise is currently only generated for SO's. However, a minimum Manufacturing impact is expected for MTI products, because these products are kept on stock. Therefore the manufacturing problem quantification will only be made for MTO products.

An issue concerning the quantification of the Manufacturing impact on delivery to first promise is that there exists no *first manufacturing promise*. The first manufacturing promise is named manufacturing due date in literature.

Definition: **First manufacturing promise** is defined as the manufacturing due date on the moment of first lead time promise generation.

Historically this first manufacturing promise is not collected. Because the past decennia the focus was on delivery to request, the manufacturing promise was considered as unimportant. Therefore, the first manufacturing promise is derived from the 1^{st} PDD (formula [1]). The internal requested delivery date is derived from the RDD. The term used at GEP for the internal requested delivery date is cTTFG.

[1] First manufacturing promise (1^{st} Mfg P) = 1^{st} PDD - (RDD - cTTFG)

The distribution lead time is equal to the difference between the RDD and the cTTFG. By detracting this lead time from the First Promised Delivery Date, the first manufacturing promise is determined.

First the relation between Manufacturing and delivery to first promise is analyzed (2.5.1). After that the relation between Manufacturing and the number of adjustments is analyzed (2.5.2).

2.5.1 Relation delivery to first promise and manufacturing

Since the first manufacturing promise has been derived, the performance concerning delivery to first *manufacturing* promise can be determined. It has been concluded that delivery to first manufacturing promise can only be measured for MTO products. Therefore all MTO product SO's are selected from the dataset of quarter 3 and 4 of 2006.

For this analysis delivery to first promise is compared with delivery to first *manufacturing* promise. Delivery to first promise (formula [2]) is affected by the manufacturing and distribution throughput time. Delivery to first *manufacturing* promise (formula [3]) is only affected by the manufacturing throughput time. Figure 2-7 shows the relation, with on the x-axis delivery to first promise and on the y-axis delivery to first *manufacturing* promise. Every dot represents an SO.

[2] Delivery to first promise = Actual Delivery Date (ADD) - 1^{st}PDD

[3] Delivery to first manufacturing promise = actual internal delivery date (aTTFG) - 1^{st} Mfg P

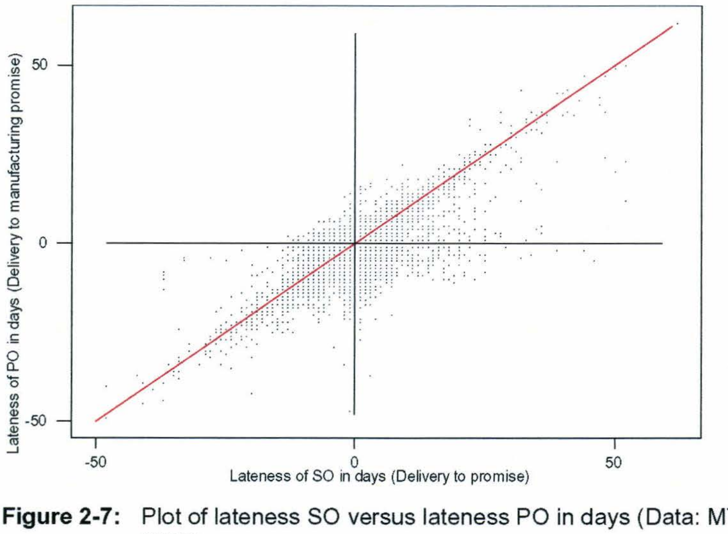

Figure 2-7: Plot of lateness SO versus lateness PO in days (Data: MTO SO, Bergen op Zoom, Q3-Q4 2006)

The red line in figure 2-7 represents the scenario where delivery to first *manufacturing* promise is the only factor for delivery to first promise. Every dot that deviates from the red line is influenced by another factor as well. The figure indicates a linear relation. Pearson's correlation coefficient is equal to 0.73 with a p-value smaller then 0.001. Hence it is concluded that statistically, a strong positive linear relation consists between delivery to first *manufacturing* promise and delivery to first Promise.

Linear regression is conducted with lateness of PO as predictor and lateness of SO as response. With an R^2 of 0.53 it can be concluded that 53% of the variation in lateness of SO can be predicted by the lateness of PO.

2.5.2 Relation adjustments in promised dates and manufacturing

It has been shown that many adjustments in PDD occur (2.4.2). This section investigates the impact of Manufacturing on the number of adjustments in PDD.

Since MTI products are generally delivered from stock, it is expected that Manufacturing has no impact on the number of adjustments in PDD for MTI products. For MTO products however, a number of adjustments can be caused by Manufacturing. To determine the impact of Manufacturing, SO's for both MTI and MTO products are compared on number of adjustments.

Figure 2-8 shows the result of this analysis. This figure shows a clear difference between MTI and MTO products. To test whether the difference between both averages is significant, a hypothesis test is conducted. With a p-value smaller then 0.001 it can be concluded that the average number of adjustments for MTO products is higher than for MTI products. Hence, it can be concluded that manufacturing does have impact on the number of adjustments in PDD.

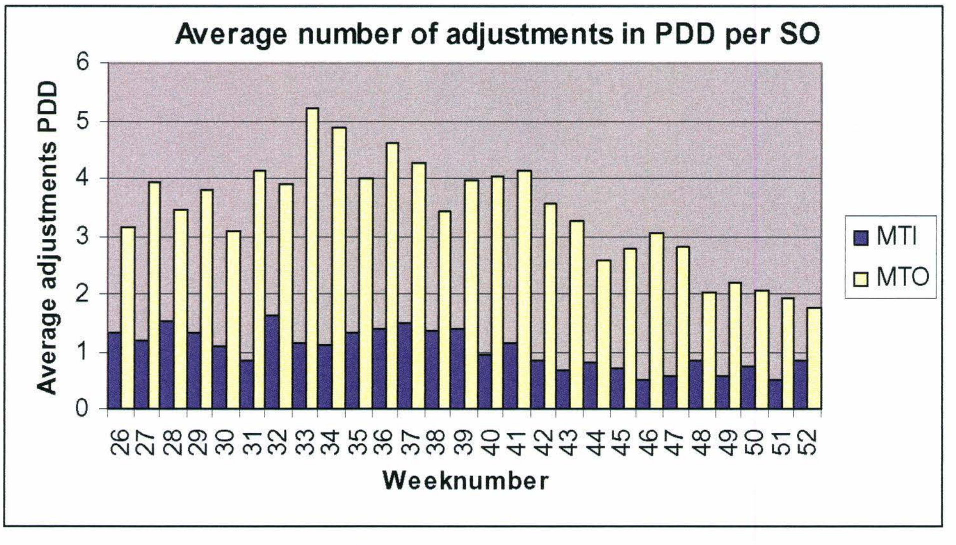

Figure 2-8: Average number of adjustments in PDD per SO for MTI and MTO separately (data: SO, Bergen op Zoom, Q3-Q4 2006)

2.6 Conclusions

Customer surveys indicate that customers give higher priority to delivery to first promise then to short lead times. Customers indicate two opportunities for improvement, being delivery to first promise and minimizing the number of adjustments in PDD. It is expected that improvement of delivery to first promise will result in less adjustments. Therefore the research topic will be delivery to first promise.

This chapter showed that both subtopics are present (2.4.1 and 2.4.2). The request for this research was to improve the on time delivery from a Manufacturing perspective. Manufacturing is defined as all activities needed that are related to a PO, from order entry until finished product. This chapter showed that currently the Manufacturing impact is significant on both subtopics (2.5.1 and 2.5.2). Therefore, the scope of research will be set to the Manufacturing perspective. In the next chapter, the delivery to first manufacturing promise is analyzed in more detail.

Part A: Analysis Phase

Create insight in delivery to first manufacturing promise

3 Analysis delivery to first manufacturing promise

It has been concluded that delivery to first *manufacturing* promise needs to improve (2.5). This chapter will analyze the delivery to first manufacturing promise in more detail. First the objective of this analysis phase will be constructed.

3.1 Objective analysis phase

Incorrect delivery to first manufacturing promise can be caused by two factors;

- The first manufacturing promise is not correct (production alignment).
- Execution has failed to produce as expected (production execution).

It is not known which of the two is the main originator for incorrect delivery to first manufacturing promise. Therefore analysis is needed to determine which of the two factors has the largest impact on first manufacturing promise.

GEP already knows the causes for failing execution, because the plant is measured on production execution. However, there is currently no insight in the causes for incorrect first manufacturing promise. GEP has named this factor production alignment. Insight is needed in the causes for production alignment.

Hence the objectives of this chapter are;

Objective 1:	Determine whether production execution or production alignment is the main originator for incorrect delivery to first manufacturing promise
Objective 2:	Create insight for production alignment in the root causes for incorrect delivery to first manufacturing promise

Production alignment and execution are both related to the life cycle of a PO. Therefore the life cycle of a PO will be explained (3.2). After that, the scope for the analysis phase is introduced (3.3). Subsequently the main originator is determined, based on a measurement tool (3.4). Then the main findings of the root cause analysis for production alignment are discussed (3.5). After that, the conclusions of this chapter are summarized (3.6). The chapter ends with the final assignment for the design phase (3.7).

3.2 Life cycle PO

The life cycle of a PO starts with order entry and ends with delivery at the warehouse. Within this life cycle, the PO can have four different states:

1. New; PO not yet scheduled on production plan (PSP)
2. Planned; PO scheduled on production plan, but not yet released for start production
3. Frozen; PO released for start production, manufacturing allowed to start production when ready
4. Finished; production finished and PO available in logistics center for shipment

These states are linked to different responsible departments. The states are graphically presented in figure 3-1, and will be discussed below. An overview of the responsible departments per given state is given in appendix D.

When a new order is entered into the system, the PO starts with the state 'New'. Before the PO can be scheduled on the detail production plan, certain conditions must be met. However, when the PO is in state 'New', no promise is given yet, so this state is considered as non-critical for performance on delivery to first manufacturing promise.

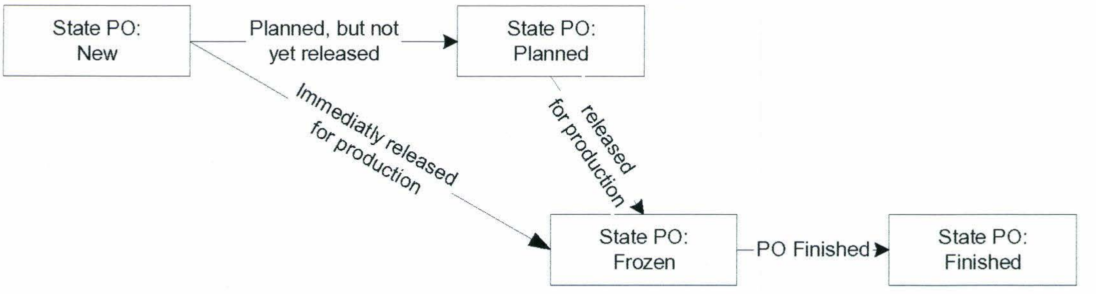

Figure 3-1: States flow of a PO

The next state that a PO will get is 'Planned' or 'Frozen'. PSP is the software that is currently used by GEP for detailed scheduling of the extruders (appendix K). Both states are directly connected with the PSP scheduling cycle. The PSP scheduling cycle is explained in appendix F. For now it is important to explain the difference between states 'Planned' and 'Frozen'.

The PO changes to state 'Planned', after a first promise has been generated. The PO changes to state 'Frozen' when it is released for production. It is possible that a PO is immediately released for production, after the first promise is generated. Therefore it is possible that the state can transform directly from 'New' to 'Frozen'. However, in most of the cases the PO will change from state 'New' to state 'Planned'.

Finally when the PO is transferred to finished goods, the PO will get the state finished PO. This is where the Manufacturing part ends.

The states are related to the manufacturing order to delivery process, as shown in figure 3-2. The three states 'New', 'Planned' and 'Frozen', split the order to delivery process in three steps. These steps are explained shortly below.

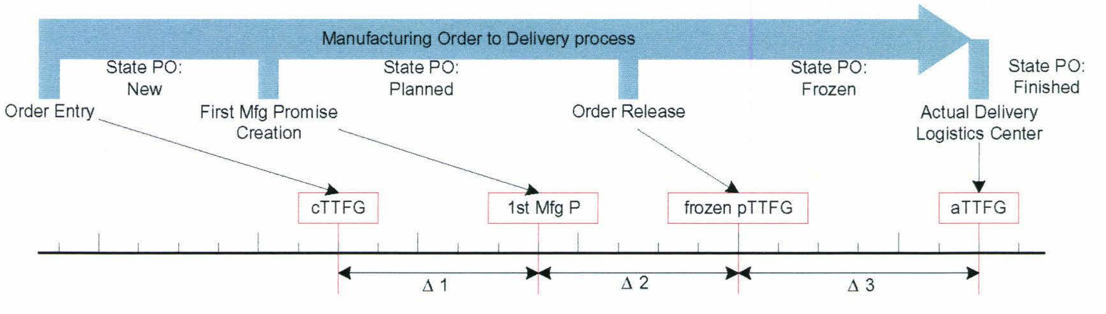

Figure 3-2: Manufacturing order to delivery process

The first step, from order entry to first manufacturing promise creation, is only influencing the lead-time, because there is no first promise made yet. All PO's having state 'New' are in the first step. These PO's remain in this state until all holds are removed. So for instance when the customer has a financial hold, the PO will not be imported to PSP. The fact that this first step does not influence delivery to first promise makes it non-critical for this research.

The second step, from first manufacturing promise creation until order release, is influencing the delivery to first manufacturing promise performance. Every change in PSP, causing the planned finish to become later then the first manufacturing promise, is creating an adjustment in promised delivery date[3]. There is no insight in how much this part contributes to the performance of delivery to first promise, not to mention the root causes for incorrect performance. In the remainder of this chapter, insight will be created into this blind spot. The

[3] Since the start of this project, some changes in this logic are made. These changes will be reflected later on.

contribution of this part is presented as Δ2, the difference between the first manufacturing promise and the planned finish on order release. This is defined as *production alignment.*

Definition: **Production alignment** is the difference in days between the first manufacturing promise and the planned finish on order release ("frozen pTTFG – 1st Mfg P")

The third step, from order release until actual delivery to the logistics center, is also influencing the first manufacturing promise performance. The plant is the only one that is responsible for this part, because they approved the frozen schedule. With this approval the plant committed to deliver the PO's to the logistics warehouse, on or before the date equal to planned finish on order release (frozen pTTFG). Because the plant is currently already measured on performance on step three, there is already a lot of insight in the drivers for bad performance. The performance on this third step is presented as Δ3, the difference between the planned finish on order release and the actual finish. This is defined as *production execution.*

Definition: **Production execution** is the difference in days between the planned finish on order release and the actual finish ("aTTFG – frozen pTTFG")

Now that production alignment and execution are formally defined, the performance can be measured. The next section will determine the scope of the analysis and subsequently the results of the measurement are discussed in section 3.5.

3.3 Scope of research

The measurement assumes that the first manufacturing promise is known. However, this date is not explicitly collected yet[4]. Therefore the first manufacturing promise date must be calculated manually, which is time consuming. Therefore the scope of analysis must be delimited.

The first delimitation is set to the Lexan plant, for two reasons. First, the Lexan plant has the biggest opportunity for improvement in delivery to first manufacturing promise. Second, it is expected that the impact will be largest at the Lexan plant, because it is accountable for 50% of the total production volume of Bergen op Zoom.

Because the data gathering is time consuming, it has been chosen to delimit the scope to a single MPS flowstream, what is basically a product group. In total there are four MPS flowstreams for Lexan. The pilot is done on the Lexan Opaque flowstream for two reasons. First, Opaque has traditionally the biggest opportunity to improve on delivery to first manufacturing promise, compared with the other flowstreams. Second, Opaque consists of almost only MTO products, what is important because delivery to first *manufacturing* promise can only be measured on MTO products.

3.4 Main originator analysis

The first objective of this chapter is to determine whether production alignment or execution is the main originator for incorrect delivery to first manufacturing promise. Corresponding measurements are Δ2 production alignment and Δ3 production execution. A measurement tool is developed to collect the measurements. This measurement tool is shortly described in appendix G.

Four months of data is collected for the Opaque flowstream, providing 760 PO's. This data is used to determine which of the two steps is the main originator to an incorrect performance on delivery to first manufacturing promise. A statistical analysis is conducted on this dataset to

[4] At the moment of finalizing this report, the Supply Chain Department implemented the first manufacturing promised date.

determine the correlation between the two steps and the performance on delivery to first manufacturing promise.

In this section a summary of the most important findings are given. The detailed results of the analysis can be found in appendix H.

From analysis it has been shown that Δ2 production alignment has a strong positive correlation with delivery to first manufacturing promise. For Δ3 production execution, also a correlation is concluded, but much less positive. Regression analysis shows that Δ2 production alignment accounts for 83.6% of the variation of delivery to first manufacturing promise and Δ3 production execution accounts for 14.2% of the variation.

From the total analysis it has been concluded that Δ2 production alignment is the main originator for incorrect delivery to first promise. Therefore it is important to gain insight in causes for incorrect production alignment. The main findings from that analysis will be presented in the next section.

Another finding is that unnecessary adjustments are generated. When a PO is late on Δ2 production alignment, it means that the planned finish on the moment of order release is later then the first manufacturing promise. This will cause an adjusted PDD, due to the promise adjustment logic (appendix E). However, in 48% of the cases, this PO was finished on time concerning the first manufacturing promise.

3.5 Production alignment root cause analysis

This section discusses the main findings from the root cause analysis for incorrect production alignment. Therefore, first incorrect production alignment has to be defined (3.5.1). After that, the most important findings from the root cause analysis are discussed (3.5.2). The production alignment root cause analysis is measured, again using the developed measure tool from appendix G.

3.5.1 Definition incorrect production alignment

The Δ2 production alignment can be separated in different levels of importance. The most desired performance is to finish the PO exact on the first manufacturing promise, because this would cause on time delivery and no stock building. The most undesired performance, on the other hand, is to finish the PO later than the first manufacturing promise. For production alignment this is defined as a *late release*. The corresponding calculation is given in formula [4]. A late release would cause an adjusted promised delivery date and possible late delivery.

Definition: **Late release** is a planned finish on the moment of order release, which is later than the first manufacturing promise.

[4] Late Release: frozen pTTFG > first Mfg P

Another undesirable performance is to finish the PO earlier than the first manufacturing promise. There are two reasons why early is considered as undesirable.

The first reason is that an early finish can be considered as a missed opportunity to deliver the goods earlier. When the promised delivery date is later then the requested, this basically means that the customer request is not fulfilled. When finally it turns out that the goods can be delivered earlier, this is considered as a missed opportunity.

The second reason is that the goods must be kept on stock when the customer does not want to be delivered earlier. Keeping goods on stock is negative for cash flow. The GEP policy is to keep the goods on stock, unless the customer requests to deliver the goods earlier. Hence it is assumed that stock-keeping costs are involved with early production.

However, not every PO can be produced exactly on the first manufacturing promise. From the PSP scheduling cycle (appendix F) it is known that the plant gives feedback on the production sequence for the next frozen period. Therefore it is possible that the plant reschedules an order from the end to the beginning of the next frozen period. A frozen period consists of approximately four days production. To give the plant the flexibility to move around orders, four days rescheduling margin is accounted in the manufacturing early measurement.

For production alignment this is defined as *early release.* The corresponding calculation is given in formula [5]. All PO's that are not late or early are on time releases, calculated by formula [6].

Definition: **Early release** is a planned finish on the moment of order release, which is more than 3 days before the first manufacturing promise.

[5] Early Release: frozen pTTFG < 1st Mfg P - 3 days

[6] On Time Release: -3 days $\leq$ frozen pTTFG - 1st Mfg P $\leq$ 0 days

On the tension field between service and stock, GE Plastics focuses on service. Therefore GEP considers late release as more undesirable then early release. Late release will be considered as leading for improving the delivery to first manufacturing promise. However, also early release can be considered as missed service. So also early release is important to be included in the remainder of this thesis.

3.5.2 Main findings

For the analysis of root causes for incorrect production alignment, five months of data from the Opaque flowstream is collected. The data collection provided 1130 PO's, of which 187 were late releases and 493 were early releases. The detailed results are presented in appendices N to Q. This section will discuss the following most important findings of the root cause analysis;

1. Current lead time promise is based on a detailed schedule, while the future state of the schedule is uncertain.
2. Extruder lead time prediction is incorrect, which causes an incorrect capacity loading profile.
3. Not every order is scheduled with a rescheduling margin
4. PSP scheduling system is inflexible

Ad 1. The current lead time promise is based on the detailed production schedule. So before the lead time promise is generated, the order must be scheduled. Within this schedule, the order is given a start and end time. However, the schedule is a constant subject of change. Therefore, also the planned end time is a constant subject of change.

Before the order will be released for production, the plant optimizes the changeover sequence for the next frozen period. The sequence optimization is primarily based on minimizing the needed cleaning time. Because sequence optimization is not based on due date, this causes late releases.

The lead time promise, based on detailed schedule information, causes slow responsiveness of lead time promise generation. New orders are imported to the schedule once a day in the beginning of the PSP scheduling cycle (appendix F). Therefore, when an order is entered after the daily import, the order is not scheduled before the next day. As a result, the first promise will also be generated the next day.

Ad 2. From the analysis it has been concluded that the extruder lead time prediction is not in line with the actual extruder throughput time. This extruder lead time prediction is used to construct a capacity loading profile of the extruder, which is the detailed schedule. The lead time promise is based on this capacity loading profile. So because the capacity loading is incorrect, the lead time promise is incorrect as well. Because the capacity loading is commonly used for order acceptance, incorrect extruder lead time prediction is not primarily an issue for scheduling based on detailed information. Therefore it is important to improve the extruder lead time prediction.

Ad 3. To deal with various disturbances in the scheduling and production process, PSP tries to schedule the order on a given target earliness. How PSP works in more detail can be found in appendix K. The target earliness is a rescheduling margin. However, the current first manufacturing promise logic (appendix J) causes not every order to be planned on target earliness. Then, when a disturbance occurs, the order will be released late.

Ad 4. From the analysis of incorrect production alignment has been concluded that the current scheduling software (PSP), is inflexible in;

- Sequence optimization
- Allocating free capacity due to time slot scheduling
- Planning across multiple extruder lines.

Sequence optimization is an optional possibility of PSP. The optimized sequence, generated by PSP, is not considered as optimal by the plant. For Lexan, the PSP sequence optimization is based on the color code. The goal of the plant is to minimize cleaning time, in order to free human resources for other tasks. The cleaning time depends on the color changeover and the use of certain additives. The additives cannot always be recognized by the color code. Hence, it is assumable that the PSP sequence optimization is not optimal.

PSP schedules orders in time slots. This means that the schedule contains *scattered free time slots*. When a new order arrives, it must be scheduled in a time slot that is large enough. Now suppose that enough free time is available on the schedule, but no single time slot that is large enough. Because PSP does not move other orders to create a single time slot that is large enough, the order will automatically be scheduled later. Result is that the lead time promise is much larger than needed.

PSP is not capable to automatically *reschedule orders to another production line*. Only the first time that the order is schedule, a line is selected. Because this results in either incorrect blocked or free capacity, the first manufacturing promise is not optimal.

A more comprehensive analysis of the most common drivers for incorrect production alignment, can be found in appendices N to Q. Also the root causes are determined in those appendices.

3.6 Conclusions

A first conclusion of this chapter is that the main originator is Δ2 production alignment (3.4). Production alignment involves orders for which a first promise is already generated, but the order is not yet released for production (3.2).

Furthermore, it has been concluded that much unnecessary promised delivery date adjustments are generated (3.4). When the order was late release, this means that a PDD adjustment has been created. However, it is shown that in almost half of those cases, the actual finish was on time concerning the first manufacturing promise.

From analysis on the most important root causes for an incorrect production alignment it has been concluded that the lead time prediction is incorrect, causing an incorrect first manufacturing promise (3.5.2).

Another conclusion is that some orders lack rescheduling margin, caused by the first manufacturing promise logic (3.5.2). The other two root causes are related to the current production planning method. Firstly, it has been concluded that a detailed schedule is too detailed for the purpose of lead time promise (3.5.2). Furthermore, the PSP scheduling system is considered as too inflexible for lead time promising (3.5.2).

3.7 Final objective part B

In this chapter, insight has been created in the main originator for incorrect delivery to first manufacturing promise. It has been concluded that production alignment is the main originator. Furthermore also insight has been created in the root causes for incorrect production alignment.

Part B of this report is considered as the design phase. The objective of this research is to improve the performance on first manufacturing promise. Probably the most important conclusion from this paragraph made is that the current prediction model is incorrect, because it directly causes an incorrect first promise. In general capacity loading is elementary for order acceptation and first promise generation. Because the current prediction model is not adequate, the model must be improved. Therefore, the first objective of part B is;

Objective 1: Design a prediction model that improves the extruder lead time prediction and include a procedure to determine correct parameters, corresponding to the model.

After the capacity loading is more accurate, also the other most important root causes must be improved. In this chapter it has been concluded that the most important root causes are related to the production planning or the lack of margin for rescheduling. Therefore the second objective of part B is;

Objective 2: Design a planning method to determine a first manufacturing promise that is accurate in 90% of the cases regarding manufacturing on time

In the next chapters it will become clear if this 90% manufacturing on time is feasible.

Part B: Design Phase

Improve manufacturing delivery to first promise

4 Improve lead time prediction model

It has been concluded that the main originator for delivery to first manufacturing promise is Δ2 production alignment (3.4). Δ2 production alignment is related to the state 'Planned', which was defined as scheduled, but not yet released for production (3.2). It has been concluded that an incorrect extruder lead time prediction is one of the most important root causes, concerning an incorrect production alignment (3.5). Generally, order acceptance and lead time promise is based on the capacity loading, regardless of the lead time strategy. Therefore, it is important to be more accurate in lead time prediction. Hence the objective of this chapter reads;

Objective: Design a prediction model that improves the extruder lead time prediction and include a procedure to determine correct parameters, corresponding to the model.

To create insight in the accuracy of different prediction models, a stochastic model is constructed (4.1). This stochastic model will also be used to analyze the impact of predictability scenarios of the current production process. First an model is constructed that predicts exactly on the mean. This model is named the enhanced model (4.2). After that, the accuracy of the current prediction model is analyzed (4.3). Subsequently, the possibility of optimizing the parameters for the current model is analyzed (4.4). This chapter ends with the discussion of the conclusions (4.5).

For both the enhanced and optimized current model, procedures are developed to determine the involved parameters. All work in this chapter is related to extruder LEX-17, of the Lexan plant in Bergen op Zoom. The procedures however will be applicable to all other extruders as well.

Although the research is focused on the performance on Δ2 production alignment, it is expected that also Δ3 production execution will improve due to a better prediction model. After all, when the production is executed as planned, the order will be finished as planned. As a result, also Δ2 production alignment will become more stable when the prediction is more reliable.

4.1 Stochastic model

GE Plastics considers the extruder as the bottleneck of the compounding process. Therefore the scheduling software PSP is focused on the planning of extruders. Because insight is needed in the predictability of the extrusion process, a stochastic model is constructed of the extruder throughput time. This stochastic model will be used to analyze different scenarios of predictability. Furthermore, this stochastic model will be used in the next sections, to analyze the prediction accuracy of different prediction models, for a given order set. This analysis is done for extruder LEX-17.

The stochastic model will model the extruder throughput time of an order. This throughput time consists of two parts, the changeover time and the run time.

Definition: **Changeover time (COT)** is the time between the extrusion start of an order and the extrusion end of the previous order.

Definition: **Run time (RT)** is the extrusion time of an order.

Because both parts are different processes, both are modeled separately. First the changeover time will be modeled (4.1.1), followed by the run time (4.1.2).

4.1.1 Changeover time

The changeover time (COT) is the time needed between extruding two orders. Therefore, it does not only include all needed activities for physically changing over the extruder, but also other activities. In example, a product bin must be available for collecting the products. In the Lexan plant, every extruder has two product bins. For as long as both bins are occupied, extrusion cannot start with the following batch.

Orders are sequenced based on cleaning time (3.5.2). This sequence dependency could indicate that the changeover time depends on cleaning time as well. However, no convincing relation between cleaning time and changeover time has been found. Therefore it is assumed that all changeover times come from the same probability distribution.

To determine the type of probability distribution, a probability plot is made in Minitab. The result is in figure 4-1. This figure indicates that the changeover time is possibly lognormal distributed. To verify if this distribution is indeed a good fit, a Chi-square test is conducted. The result of this Chi-square test with 20 degrees of freedom is that H0: The distribution of changeover times is lognormally distributed, cannot be rejected, since $\chi_0^2 = 24.5 < \chi_{0.05,20}^2 = 31.4$.

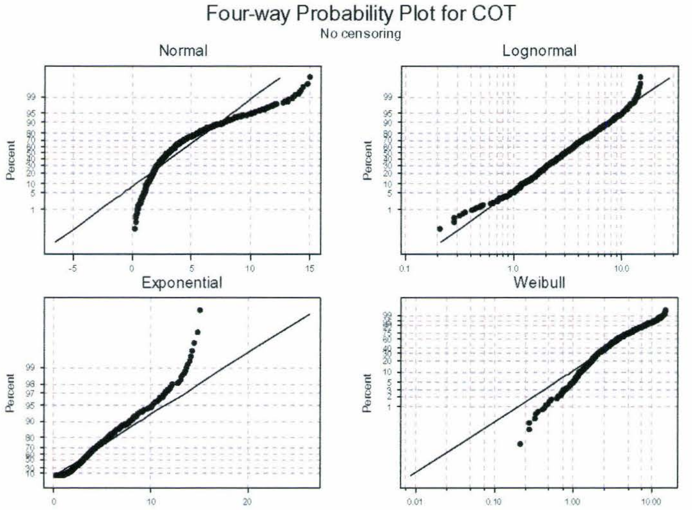

Figure 4-1: Four-way probability plot for changeover times in hours

Therefore it is assumed that the changeover time is lognormally distributed with a mean of 4.17 hours and a variance of 14.21 hours. The corresponding cumulative distribution function for Changeover Time (COT) in hours is

$$F(COT) = P\left[Z \le \frac{\ln(COT) - 1.131}{0.772}\right] = \Phi\left[\frac{\ln(COT) - 1.131}{0.772}\right]$$

4.1.2 Run time

The run time (RT) is defined as the extrusion time of an order. This includes all disruptions that occur between the extrusion start and end of an order. Planning has to take these disruptions into account. Therefore, the stochastic model takes these disruptions into account as well. The

The run time is related to the produced quantity. An extruder has a minimum production quantity, due to blending, which is the preceding production. Blending has a minimum blend capacity. The schedule consists of PO's. A PO quantity can be smaller than this minimum production quantity. Hence, the minimum production quantity must be included in the model. Therefore the PO quantity is transformed to a production quantity, by formula [7].

[7] $tQ_{PO}[kg] = \max(Q_{PO}[kg]; MPQ[kg])$

The production quantity tQ_{po} is equal to the maximum of the PO quantity Q_{po} and the minimum production quantity MPQ. From data analysis it has been concluded that the minimum production quantity is 2409 kg for LEX-17.

An extruder produces with a certain speed, defined as the *run rate*. The run time is based on the production quantity and run rate, by formula [8].

Definition: **Run Rate (RR)** is the production speed of an extruder in kilogram per hour

$$[8]\quad RT(tQ_{PO})[hr] = \frac{tQ_{PO}[kg]}{RR[kg/hr]}$$

However, the run rate is not a constant. To investigate the relation between the production quantity (tQ_{PO}) and the run rate (RR), both variables are plotted in figure 4-2. The figure indicates that the variance in run rate is larger for smaller production quantities. This behavior can be explained by the fact that disruptions in production are one of the reasons for variation in run rate. Now when a small PO is produced, the duration of the disruption can only be distributed over a small number of kilograms, causing the run rate to go down for that PO. On the other hand, the absolute impact of the run rate on runtime is much less for small PO's than for large PO's. Therefore, the assumption is made that all run rates are drawn from one distribution.

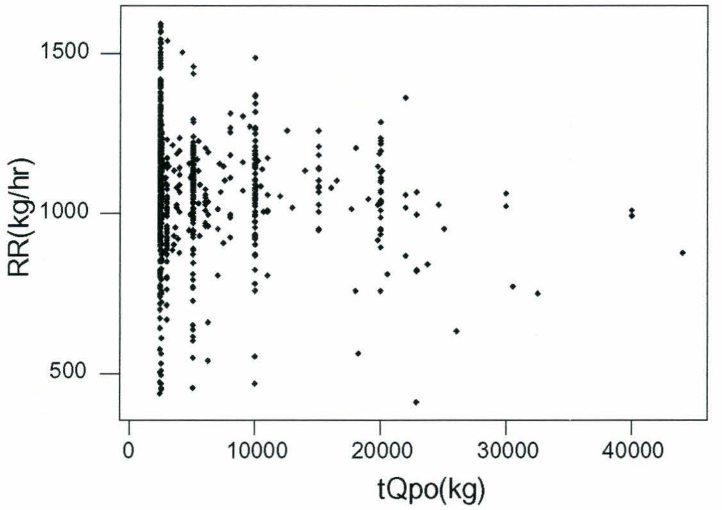

Figure 4-2: Run rate (RR) plotted against transformed quantity of the PO (tQpo)

Probability plotting indicates that the run rate is normally distributed, with mean 1074 kg/hr and standard deviation 193 kg/hr. To investigate whether the run rate is indeed normally distributed, a Chi square test is conducted to test for normality with mean 1074 kg/hr and standard deviation 193 kg/hr. The results of this test can be found in appendix R. From this test it can be concluded that there is no evidence that the distribution is not normal given mean and standard deviation, with;

$$\chi_0^2 = 40.6 < \chi_{0.05,30}^2 = 43.8$$

Therefore it is assumed that the run rate is normally distributed with a mean of 1074 kg/hr and a standard deviation of 193 kg/hour. The corresponding cumulative distribution function for the run rate in hours is given in formula [9].

$$[9]\quad F(RR) = P\left[Z \leq \frac{rr-1074}{193}\right] = \Phi\left[\frac{rr-1074}{193}\right]$$

Now that the distribution function for the run rate is known, it must be translated to a distribution function for the runtime. Recall the formula [8] for the run time. Since the run rate is normally distributed, the run time can be transformed to the cumulative distribution function given in formula [10]. Note that the run time is not normally distributed.

$$F\left(RT\left(tQ_{PO}\right)\right)=P\left[\frac{tQ_{PO}}{RR}\leq rt\left(tQ_{PO}\right)\right]=P\left[RR\geq\frac{tQ_{PO}}{rt\left(tQ_{PO}\right)}\right]$$

[10]

$$=P\left[Z\geq\frac{\frac{tQ_{PO}}{rt\left(tQ_{PO}\right)}-1074}{193}\right]=1-P\left[Z\leq\frac{\frac{tQ_{PO}}{rt\left(tQ_{PO}\right)}-1074}{193}\right]=1-\Phi\left[\frac{\frac{tQ_{PO}}{rt\left(tQ_{PO}\right)}-1074}{193}\right]$$

To be able to investigate the accuracy of a prediction model, the variance in extruder throughput time must be determined. However, both the changeover and run time have an own variance, and the variance of the run time depends on the production quantity (appendix S). Therefore, the stochastic model is simulated in the simulation software application Enterprise Dynamics. Reporting of this simulation can be found in appendix U. The next section discusses the main findings.

4.1.3 Main finding simulation model

Changeover time has a large opportunity for increasing predictability and capacity. Firstly, the extruder is in a changeover for 40% of the time. Therefore, changeover time has a large opportunity for capacity increase, due to reduction of the mean.

From the simulation model it has been concluded LEX-17, that the variance of the run time is equal to the variance of the changeover time at 18.500 kg. The relation between the variance of both processes and the quantity of a PO is shown in figure 4-3. With 80% of the PO's smaller than 10.000 kg and an average production quantity of 5,600 kg, it has been concluded that the focus for LEX-17 should be on variation reduction in changeover time.

Therefore it is recommended to focus on decreasing the mean and variance of changeover time, concerning predictability.

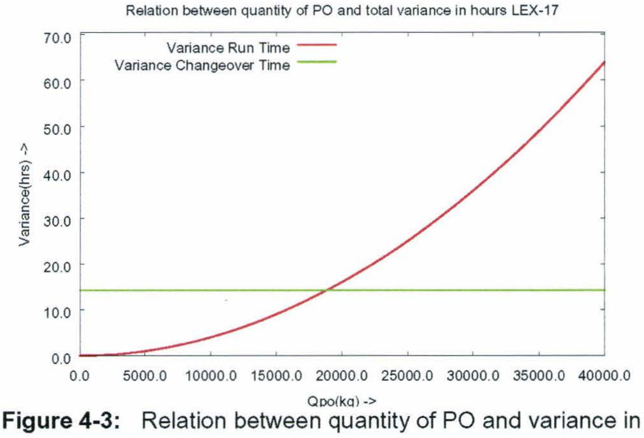

Figure 4-3: Relation between quantity of PO and variance in hours LEX-17

However, the objective of this research is to improve the prediction model. For that reason, a prediction model is constructed, which is predicting exactly on the mean. This model is named the enhanced prediction model (4.2). After that the current model is analyzed with the current parameters (4.3). Subsequently the parameters of the current model are optimized (4.4).

4.2 Enhanced prediction model (MPQ scenario)

In this section a prediction model is constructed that plans exactly on the mean. The result will be that the accuracy is reduced to only the variance of the throughput time. This is done based on the stochastic model used in the previous section. The enhanced prediction model will be named MPQ scenario, after the fact that it will include the minimum production quantity.

Basically, when it is not possible to link the variance in changeover and run times to specific PO characteristics, it is not possible to exactly predict the actual changeover and run times for a single PO. Because it is not possible to exactly predict the actual changeover and run times, it is chosen to use the mean values. However, there is much variance in the changeover and run times, so also that variance must be dealt with. In this enhanced scheduling model, this will be done by use of slack time. But before discussing the slack time, the model for changeover and slack time will be explained. The procedure to determine the correct parameters is explicitly given in appendix W.

Changeover time
In the sections 4.1 it was assumed that all changeover times were drawn from the same probability distribution. In reality changeovers are grouped by changeover codes. For instance there are 13 actively used changeover codes for LEX-17. First it must be checked whether the different changeover groups do really come from the same probability distribution.

Because the changeover time will be scheduled on the mean, the first check is whether there is a difference in mean changeover time between the different changeover codes. Since the changeover times are lognormal distributed, two sided two sample t-tests are performed on the different changeover groups, based on ln(COT). From this test it can be concluded that only the means of N and A mutually and versus the others, can be rejected as coming from the same distribution.

The two exceptional changeover codes as well as the remaining changeover codes together, are fitted again. From this fitting it can be concluded that all changeover times are still lognormal distributed. Code N with location 0.879 and scale 0.794, Group A with location 1.083 and scale 0.669 and the remaining codes with location 1.499 and scale 0.716. This will be the input of the simulation model as well, to distinguish the different changeover codes.

Based on the distribution above, the changeover times for the different groups will be set equal to the average. This is considered as the optimal setting, when slack time is used to deal with variation. This means that for group N, the average is set to 3.30 hrs, for group A the average is set to 3.70 hours and for the remaining groups, the average is set to 5.78 hours.

Run time
In the previous sections it was already shown that the main predictor for run time was the minimum production quantity and the requested quantity. Therefore this scenario is named the Minimum Production Quantity scenario, or MPQ scenario.

The average run rate is known. Nevertheless, this is not equal to the run rate corresponding to the average run time, because of the difference in units of measurements in both averages. The run rate corresponding to the average run time for LEX-17 is equal to 1038 kg/hr. Based on this run rate the expected run time will be calculated.

The MPQ can be determined by calculating the average produced quantity for all very small PO's. The MPQ for LEX-17 is equal to 2409 kg. Based on these average values the run time for the MPQ scenario will be modeled by the formula

$$RT_{MPQ}(Q_{PO}) = \frac{\max(Q_{PO};MPQ)}{RR} = \frac{\max(Q_{PO};2409)}{1038}$$

Q_{PO} = Quantity of PO [kg]
RT_{MPQ} = Run time [hr]

MPQ = Minimum Production Quantity [kg]
RR = Run rate [kg/hr]

Slack time
Now the average values for changeover and run time are calculated for the order set. However, to be able to give a feasible first manufacturing promise, the prediction model must deal with the variance as well. For a first manufacturing promise, the PO has to deal with the variance of all PO's that have to be produced in front of it. So the total variance in front of a PO is dependent of the PO's produced in front. Based on the analysis from section 4.1 it is expected that the total variance is dependent on the number of PO's in front and the quantity per PO.

It can be concluded that there is a relation between the expected variance in front of a PO and the total expected duration of the order set in front. It is assumed that all PO's are planned directly after each other. In other words, the line is fully occupied. To find an answer on this relation, simulations with order sets of different number of days are created, again based on the dataset of Q3 2006 to Q2 2007.

The changeover time is adjusted to the three given distributions in this section. Based on historic data, the fraction of changeovers per changeover code is determined to be 0.394 * N, 0.225* A and 0.381* the rest. This time the prediction model will calculate the expected changeover and run time.

Now the question is how much variance this prediction model must deal with. It is expected that a little less variance will occur, compared with the stochastic model, because now the changeover times are divided into three subgroups for LEX-17. The relation between number of days order load and total variance is linear, because the total variance for two independent stochastics is equal to its sum.

The amount of slack needed for a line depends on order load of the line and the reliability of the slack. It is assumed that the order mix is known and equal to the dataset Q3 2006 to Q2 2007. The simulation model is used to determine the needed slack for the given order mix for several different reliabilities. The result is plotted in figure 4-4.

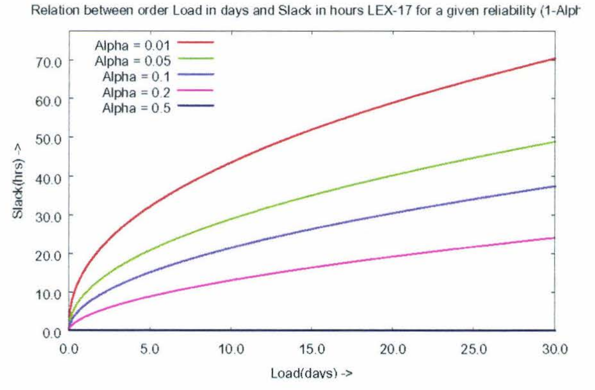

Figure 4-4: Relation between MPQ order load in days and slack in hours LEX-17 for a given reliability

In the current situation, slack time is planned after each frozen period. Practically this means for Lexan that after every 4 days a slack time unit is built in the schedule. Based on the enhanced prediction model, this would mean that for 95% reliability, the slack time unit would have to be approximately 19 hours.

However, besides for the variance in extrusion times, slack time is currently also used for remakes and insertions. A remake is a PO that is already produced but not yet fully correct. Reasons for remakes are underproduction and reject. Underproduction means that not enough was produced and rejects means that the produced products did not meet the quality standards. An insertion is a PO that is not planned according to the first come first schedule rule.

The minimum average time consumption for a remake is equal to 6.5 hours. From historic data can be concluded that LEX-17 has on average 1.5 remakes due to reject, causing at least an average production delay of 10 hours per week. Besides remakes for reject there are remakes for underproduction. Most remakes are small, because often only a part of the PO must be remade. The fact that remakes are often small causes that the impact of the changeover time on the total extruder time is large. This is another argument to focus on reduction of the mean and variance of the changeover time.

Conclusion for slack time is that, given the current probability distributions for changeover and run time, together with the fact that slack time is also used for remakes and insertions, very much slack time must be built in with respect to the four day frozen period, for a 95% reliability. Most important focus, with respect to capacity and prediction reliability, should be on reducing the mean and variance of the changeover times. Furthermore it is important for the reliability of the schedule to determine a policy for the maximum number of insertions and remakes per period.

4.3 Current prediction model with current parameters (PSP scenario)

In the previous section an enhanced prediction model has been constructed. In this section, the current prediction model with the current parameters will be discussed, named PSP scenario. PSP is the current scheduling software. The structure of this section will be the same as the previous section, so first the changeover and run time are analyzed and after that the needed slack time for this model, with respect to variance in extruder time.

Changeover time
In the current prediction model, changeover times are not managed, even though it is possible. In other words, the importance of accurate changeover times in planning is underestimated. On top of that, the changeover times are used to determine a correct sequence in planning, by minimizing total changeover time. This means that a requirement for the changeover times is, that the current sequence in planned duration must be kept the same.

The twelve changeover codes differ in changeover times in the range of 50 minutes to 270 minutes. However, the average planned changeover time for the year data was equal to 100 minutes. Comparing the 100 minutes to the 240 actual, it is concluded that the average difference in planned and actual changeover time is 140 minutes per changeover. Historically there are on average 7.5 PO's per frozen period, what means an average difference of approximately 19 hours per four days-frozen.

It is expected that a lot is to be gained by updating the changeover times to reality as done in the MPQ scenario. However, the difference in changeover times between planned and actual is currently compensated by the run rate, as will be explained in the run time section of this section.

Run time
In the current prediction model, run times are calculated via the following formula

$$RT_{PSP}(Q_{PO}) = \frac{(Q_{PO} * I_Q + Q_{STD}) * I_{RR}}{RR}$$

$$I_Q = \left(1 - \frac{If_Q}{100}\right)$$

$$I_{RR} = \left(1 - \frac{If_{RR}}{100}\right)$$

Q_{PO} = Quantity of PO [kg]
RT_{PSP} = Run time [hr]
If_Q = Inflation factor Quantity [1]

Q_{STD} = Standard increment quantity [kg]
If_{RR} = Inflation factor run rate [1]
RR = Run rate [kg/hr]

This function is a first power function with one variable, so therefore the function is linear. The function can be rewritten to

$$RT_{PSP}(Q_{PO}) = \frac{(Q_{PO} + Q'_{STD})}{RR'}; \text{ with } Q'_{STD} = \frac{Q_{STD}}{I_Q} \text{ and } RR' = \frac{RR}{I_Q * I_{RR}}$$

This rewriting shows that the inflation I_Q is directly influencing both the standard increment quantity and the run rate. The inflation I_{RR} is directly influencing only the run rate. However, the run rate is also influencing the standard increment quantity, so I_{RR} is also indirectly influencing the standard increment quantity. Furthermore, the rewriting shows that it is possible to use only two parameters, what would be more logical for calculating a linear function.

Writing the function as a standard linear function shows that

$$RT_{PSP}(Q_{PO}) = a + b * Q_{PO}; \text{ where } a = \frac{1}{RR'} = \frac{I_Q * I_{RR}}{RR} \text{ and } b = \frac{Q'_{STD}}{RR'} = \frac{Q_{STD} * I_{RR}}{RR}$$

For the current settings, the only parameter that is managed is the inflation run rate I_{RR}. This in itself makes it difficult to find an optimal solution, because of the interaction with the other parameters. On top of that, the current procedure for determining the settings is compensating the difference in changeover time by adjusting the I_{RR}. This means that the slope will be influenced by this compensation as well. Because the quantity is the most important predictor of run time, this changeover time compensation is compensated very much by large PO's and almost not by small PO's. This is graphically shown in figure 4-5.

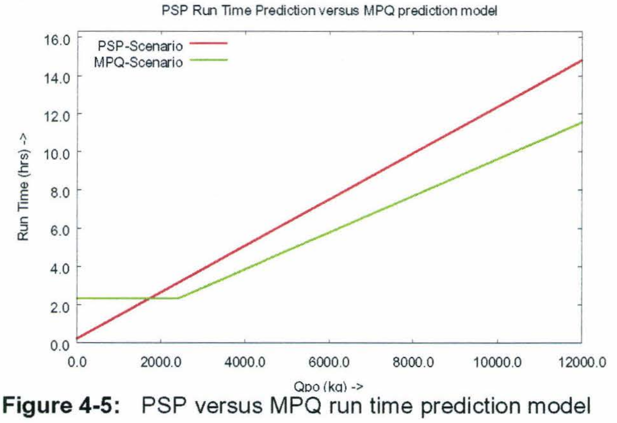

Figure 4-5: PSP versus MPQ run time prediction model

A second issue that is also shown in figure 4-5, deals with the minimum production quantity. With the current settings the y-intercept is equal to approximately 13 minutes. So a PO of 25 kg will schedule 15 minutes run time in current model. The actual run time for a PO of 25 kg is 2.3 hours, because of the minimum production quantity. Within the current formula, it is not possible to model this minimum production quantity.

Slack Time

The current parameter for slack time is set to 18 hours per four days frozen period. As already mentioned in the previous section, this slack time is used for variance in extrusion times, remakes and insertions.

The amount of slack needed for a line depends on order load of the line and the reliability of the slack. It is assumed that the order mix is known and equal to the dataset Q3 2006 to Q2 2007. Again the simulation model is used to determine the needed slack for the PSP scenario for several different reliabilities, given the order mix. The result is plotted in figure 4-6. The needed slack for the four days frozen schedule in the PSP scenario is equal to 32.5 hours, what is much more than the 19 hours of the enhanced model. Figure 4-6 shows that the prediction model is not on the mean, because at 50% reliability the line is not equal to zero slack.

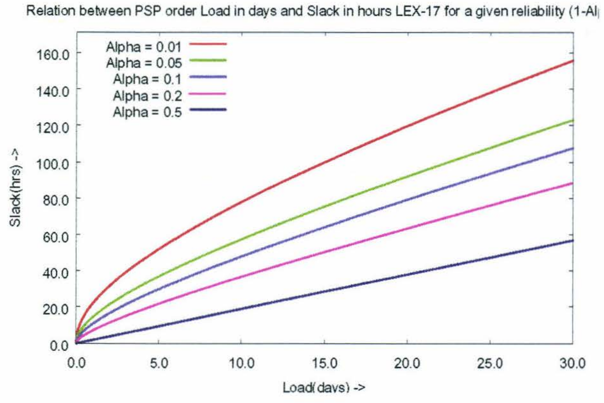

Figure 4-6: Relation between PSP order Load in days and Slack in hours LEX-17 for a given reliability

4.4 Current prediction model with optimized parameters (OPT scenario)

Given the insight that is created in the previous section, there is an opportunity to optimize the current models parameters. This optimization will not be as good as the MPQ scenario, but has the advantage that no code changes are needed in the calculation, but only parameters need to be adjusted. This must be done by adjusting the changeover and run times to reality. This scenario is named the OPT scenario. The procedure to determine the correct parameters is explicitly given in appendix W.

Changeover time
The changeover times from the MPQ scenario can be translated directly to the OPT scenario.

Run Time
The current prediction model uses a linear function to determine the run time, so it is not possible to include the minimum production quantity explicitly in the current model, without adjusting the formula. However, the changeover times do not need to be compensated anymore, because these are set to average.

In the previous section it was already suggested that the formula of PSP can be simplified to only two parameters, without adjusting the formula. This is accomplished by setting the two inflation factor parameters to zero. Now to deal with the minimum production quantity within the current prediction model is to calculate a linear function, which will minimize the total difference between the run time in the MPQ prediction model and the run time in the current prediction model. This is done via the following model

$$\min \sum_{PO=1}^{N} \left| \left(\frac{Q_{PO} + OQ_{STD}}{ORR} - RT_{MPQ}(Q_{PO}) \right) * TTE_{PO} \right|$$

$$with\ TTE_{PO} = \frac{\overline{COT} + RT_{MPQ}(10.000)}{\overline{COT} + RT_{MPQ}(Q_{PO})} = \text{Ten Ton Equivalent factor for PO [1]}$$

Decision variables:
ORR = Optimized parameter run rate [kg/hr]
OQ_{STD} = Optimized parameter standard increment quantity [kg]

Constants:
$\overline{COT}$ = Average changeover time [hr]

The ten-ton equivalent factor is used to be able to compare small PO's with large PO's. This is best explained by an example. Let's take a PO of 3 ton and a PO of 10 ton. The production time for the 10 ton PO will be approximately 14 hours and the production time for the 3 ton PO will be approximately 7 hours. Now a difference of 2 hours for the 10 ton PO is as important as 1 hour for the 3 ton PO, because 2 PO's of 3 tons can be produced in the same time as 1 PO of 10 ton. Hence, the TTE_{PO} for 3 ton is equal to 2.

A year of data is put into the model to determine the optimized parameters. The model is solved using a branch and bound method written in Visual Basic. Results from the model for LEX-17 are an OQ_{STD} of 1480 kg and an ORR of 1248 kg/hr.

Slack Time

The amount of slack needed for a line depends on order load of the line and the reliability of the slack. It is assumed that the order mix is known and equal to the dataset Q3 2006 to Q2 2007. Again the simulation model is used to determine the needed slack for the OPT scenario for several different reliabilities, given the order mix. The result is plotted in figure 4-7. The needed slack for the four days frozen schedule in the PSP scenario is equal to 21 hours, what is rather close to the 19 hours of the enhanced model. Figure 4-7 shows that the prediction model is not exactly on the mean, because at 50% reliability the line is not equal to zero slack. Apparently, setting the current prediction model to the mean will cause a larger variance than this optimized model. However, the OPT scenario is much closer to the mean than the PSP scenario is.

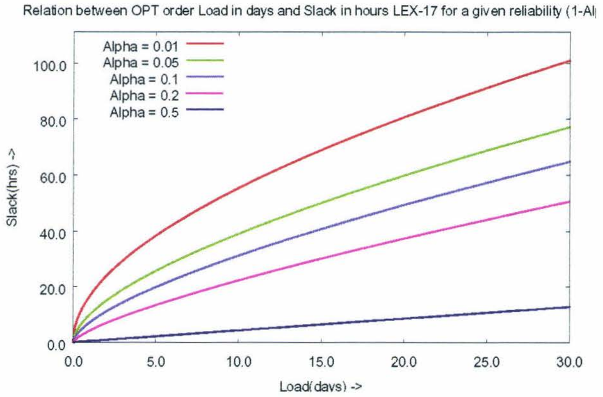

Figure 4-7: Relation between OPT order Load in days and Slack in hours LEX-17 for a given reliability

4.5 Conclusions

The accuracy of extrusion lead time can be improved by less variance in the process and a better prediction model. This research focuses on improving the prediction model. However, from the simulation it has been concluded that the changeover times have a large opportunity for increasing predictability as well as capacity (4.1.3). Because of the current variance in changeover times, it is difficult to control the lead time. Therefore it is recommended to focus on reducing the mean and variance of changeover times.

Because this research is on improving the prediction model, three prediction models are analyzed, being the enhanced (MPQ), current (PSP) and optimized current (OPT). Besides the prediction models, slack time is used to deal with deviations from the prediction model. The enhanced (MPQ) model is planning exact on the mean values and therefore slack for extrusion time does only deal with the deviations from these mean values. Drawback of the MPQ model is that it needs an adjustment in the calculation of PSP software. Because PSP will be replaced in the near future, it is expected that adjusting this calculation will be considered as not valuable. Therefore it is recommended to use this information as input for a new scheduling system.

In the current (PSP) model changeover times are not maintained and controlled, even though this is possible for the model. This causes an imbalance between planned and actual, what is compensated by the run time. However, because the run time is related to the quantity of the PO, this is not compensated fairly. Furthermore, the current model does not consider a minimum production quantity. The needed slack for extrusion time is therefore much higher than in the enhanced model, being 32.5 hours versus 19 hours.

In the optimized current (OPT) model, the changeover times are not maintained. Also the minimum production quantity is taken into account by minimizing the difference between the MPQ prediction model and this OPT prediction model. The needed slack for extrusion time for the OPT model is close to the needed slack for the MPQ model, being 21 hours versus 19 hours. However it is expected that the large impact of the changeover time is the major cause for this small difference between the two prediction models. Therefore it is recommended to analyze the performance of the OPT model versus the MPQ model lines with less impact of changeover times.

The slack time in the schedule is currently not only used to deal with the difference between actual and planned extrusion time, but also for remakes and insertions. It is recommended to analyze the impact of these remakes and insertions. A quick analysis is indicating that for LEX-17 the average impact of remakes due to rejects is equal to 10 hours per week, but this is still a rough estimate. Besides this remakes due to rejects, there are also remakes due to undermake.

All over this chapter it is concluded that the changeover times are the main source for variance in predictability for LEX-17. Furthermore, reduction of the average changeover time can be considered as the major opportunity for increasing the capacity. Therefore it is recommended to focus on reducing the mean and variance in changeover times for LEX-17.

5 Improve first manufacturing promise

In chapter 4, an improved prediction model was presented for the extrusion lead time of a PO. Furthermore an analysis is made on the variance in total extrusion throughput time for a set of PO's. Now that there is insight in the predictability and variance in lead-time of a set PO's, the foundation is created to determine a more realistic first manufacturing promise. This chapter will discuss the possibilities to improve delivery to first manufacturing promise.

Objective: Design a planning method to determine a first manufacturing promise that is accurate in 90% of the cases regarding manufacturing on time

Four important root causes are determined for production alignment (3.6). After improving one, being incorrect lead time prediction, still three of four need improvement;

1. Not every order is scheduled with a rescheduling margin
2. Current lead time promise is based on a detailed schedule, while the future state of the schedule is uncertain
3. PSP scheduling system is inflexible

Root cause 1 is related to the first manufacturing promise logic. Root causes 2 are related to the production planning system.

The first manufacturing promise is named lead time promise in common literature. Both terms will be used interchangeably in this chapter. This chapter will start with a literature review on lead time promising (5.1). Subsequently, the initial GEP situation will be discussed (5.2). Partially based on insight created in production alignment, changes have been made to this initial situation. One of these changes is related to the root cause *rescheduling margin.* In section

in the first manufacturing promise determination. In appendices N to Q root causes and drivers for performance on Δ2 manufacturing alignment are presented.
Based on that insight, some changes are made in first manufacturing promise logic.

However, only the initial situation will be discussed. Thereafter the recent changes are discussed and finally a recommendation will be done on how to design the procedure for lead-time promising (5.4).

5.1 Literature review

The lead time promise is a result of the production control structure. The production control structure of GEP is divided over three levels. In the literature this is called a hierarchical production control structure. The concept of hierarchical production control will be explained first (5.1.1). Special attention is given to hierarchical production control in batch process industries. Subsequently literature on order acceptance and scheduling is discussed (5.1.2), because this is where the lead time promise is generated.

5.1.1 Hierarchical production control

Production control is defined as the coordination of supply and production activities in manufacturing systems to achieve specific delivery flexibility and delivery reliability at minimum costs (Bertrand et al., 1990). A production control concept is a description of and relations between all decision functions regarding the management of materials flow and capacity resources.

Several researchers have regarded hierarchical control structures (e.g. Bertrand et al. 1990; Schneeweiss, 1995; Raaymakers 1999). The key idea of hierarchical production control is that different decisions are made at different levels in the organization. Namely, different decisions regard different time horizons, and therefore different kinds of information. For example, order acceptance and capacity loading decisions may need to be made at a moment at which not all information is available on the future status of a production system. In that case, aggregate information can be used to make those decisions. Later in time, when all detailed information comes available, the decisions on the actual execution of a job can be made.

Raaymakers (1999) developed a hierarchical production control structure for batch processing industries, as shown in figure 5-1. This production control structure is limited to the coordination of capacity resources between supply and demand. Raaymakers recognizes three decision functions, distributed over three hierarchical levels. Each decision function is assigned an objective, resulting from the objective of the overall production system. The objective of the overall system is to maximize the resource.

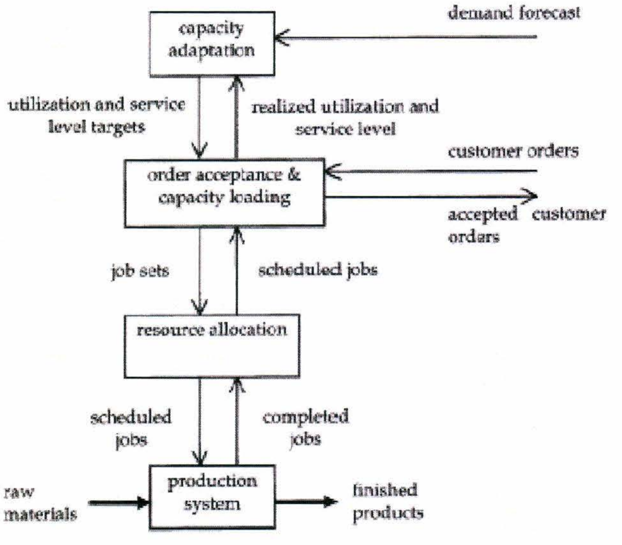

Figure 5-1: Hierarchical production control structure for process industry (Raaymakers, 1999)

Following the concept of Raaymakers (1999) the three decision functions are capacity adaptation [long term], order acceptance and capacity loading [medium term] and resource allocation [short term]. Determining a lead time promise is typically a medium term decision, because not all information is known on the future state of the production system. This medium term decision can be evaluated in different ways. It is possible to construct a detailed schedule each time a customer order arrives or to use aggregate information. An advantage of accepting customer orders based on aggregate information is that it is less time consuming and less sensitive to production and demand disturbances. At GEP, the order acceptance decision is based on a detailed schedule.

Even though they are closely related, literature distinguishes production planning and scheduling. According to Kallrath (2003) planning is typically associated with a longer planning horizon and involves less detail, whereas scheduling is associated with the prices timing and sequencing of individual operations. Translating this to the concept of Raaymakers (1999), the planning function is equal to the order acceptance and the scheduling function is equal to the resource allocation. The capacity adaptation in batch process industries is considered to be a long-term decision and therefore will not be discussed. The lead time determination is made on order acceptance. Because order acceptance and scheduling are closely related, the next section will discuss literature on both topics together.

5.1.2 Order acceptance and scheduling

According to Ebben et al. (2005) order acceptance is a managerial activity that deals with accepting and rejecting customer orders. Both Ebben et al. (2005) and Ten Kate(1995) state that the order acceptance and scheduling function in a company are generally separated activities. However, too many accepted orders cause the production system to become overloaded. This will result in increased lead time and orders that are delivered late. Therefore the order acceptance and scheduling functions need coordination.

Ebben et al. (2005) provide an overview of several order acceptance methods suggested in literature. Roughly literature is divided into order acceptance based on detailed schedule information or on aggregated information. The difference between these two approaches is the reservation of capacity. In the detailed approach, the capacity assignment to time periods is not fixed once an order is accepted, because rescheduling is done every time a new order arrives. In the aggregate approach the capacity for an order is reserved once it is accepted, and this is not changed afterwards.

It is concluded by several authors that in cases of little slack and high workload, order acceptance based on detailed information outperforms the method based on aggregate information (Wester, 1992; Ten Kate, 1995; Ivanescu et al., 2002; Ebben et al., 2005). However, both Wester (1992) and Ten Kate (1995) state that when changeover times are sequence dependent, order acceptance based on detailed information suffers from selectivity. Selectivity means that orders have a higher chance for being accepted if they fit well into the batch pattern of the actual schedule. Ivanescu et al (2005) develop a combined approach of detailed and aggregate information, the hybrid policy. They conclude that this hybrid policy that outperforms the approaches that use solely detailed or aggregate information.

Another suggestion for order acceptance is the use of fixed instead of adaptive lead times. This theory is originated from the *lead time syndrome*, first introduced by Mather and Plossl (1978). Selçuk et al (2006[1]) denotes this as the variability introduced by frequent updates of lead times. It is argued that closing the gap between lead times and actual flow times by updating the lead times results in uncontrolled order release patterns. The vicious cycle of the lead time syndrome as introduced by Mather and Plossl (1978) is visualized in figure 5-2. As lead times get larger, orders must be released earlier, queues get longer and flow times get longer which causes again larger lead times. The general consensus is that the lead time syndrome causes instability and must be avoided. Selçuk et al (2006[1]) review that this reasoning has become one of the main arguments for controlling flow times within the predetermined norms instead of forecasting them.

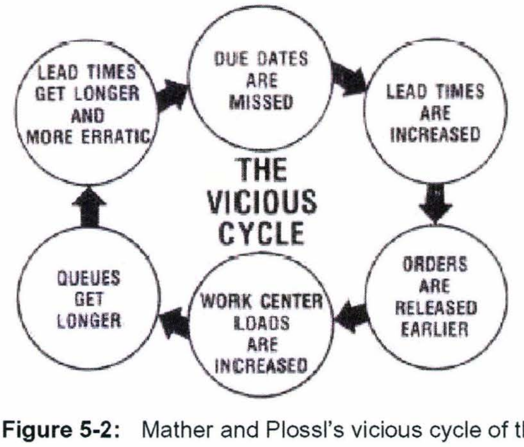

Figure 5-2: Mather and Plossl's vicious cycle of the lead time syndrome

Selçuk et al (2006[2]) analyzed the effect of updating lead times on the performance of hierarchical planning systems in a dynamic and stochastic setting. They showed that under realistic conditions updated lead times policy causes unavoidable increase in lead times and, as a result, unstable, inefficient decision making. However, for settings with low degree of variability lead time update even provides better cost performance. They indicate that currently no robust adaptive lead time strategy is known, that is stable and at the same time provides the flexibility needed.

5.2 Analysis of GEP lead time promise

The production control structure of GE Plastics is classified as hierarchical, what is shown in figure 5-3. In the Production Sales and Inventory (PSI) plan quarterly targets per product family are set with a time fence of one year. These aggregate plans define the targets to 'steer' the organization, and therefore the targets are not naturally equal to the forecast. The PSI-plan has to be updated quarterly, to adapt the targets to actual sales.

The PSI is the basis of the Master Production Schedule (MPS). The MPS is constructed per MPS flowstream. A MPS flowstream refers to a type within the product family, e.g. opaque products. The reason that MPS flowstreams are used is because production lines are managed via these flowstreams. Basically all orders belonging to the same flowstream are grouped for production on dedicated lines. The purpose of the MPS is to keep control of the targets set in the PSI. The MPS shows the available capacity per MPS flowstream versus the demand for capacity. If demand for specific flowstreams exceeds the capacity, it can be decided to change another line to this flowstream.

Bertrand et al. (1998) denotes that MPS is used to plan how much is being produced of a certain MPS item. From this description it can be concluded that GEP uses the MPS only as a tool to analyze the relation between demand and capacity. Therefore the current used MPS is purely demand driven.

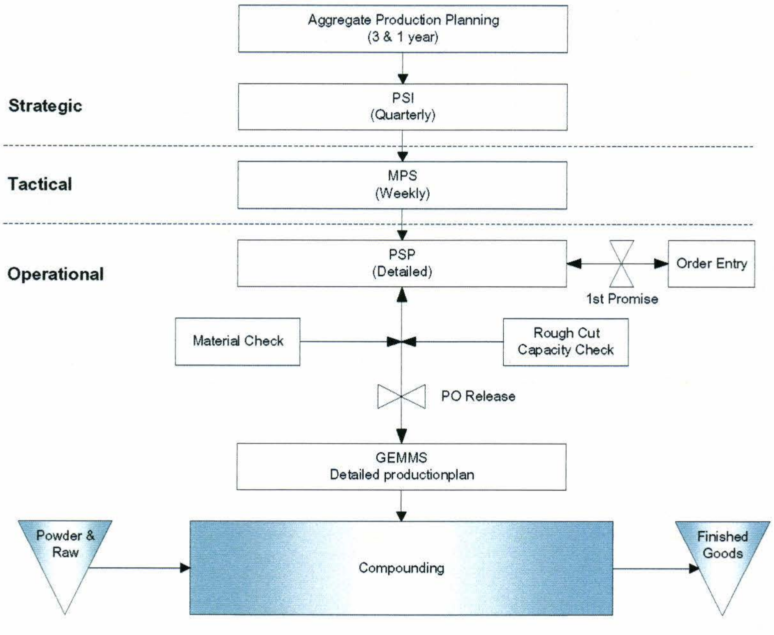

Figure 5-3: Production control structure of GEP

Literature distinguishes fixed lead times and variable lead times. Furthermore capacity loading can be performed on detailed schedule or aggregate information. So there are three possible methods to promise the lead time;

1. Fixed lead times
2. Variable lead times based on aggregate information
3. Variable lead times based on detailed schedule information

At GE Plastics, the lead times currently are based on capacity loading of detailed schedule information and therefore variable. Furthermore, when GE Plastics cannot commit to the requested lead time, a new lead time is proposed. This causes that the order will only be rejected when the customer and GE Plastics do not agree upon the promised delivery date. Hence, the order acceptance function in this context is mainly involved with the promised lead time. Below, the three possible lead time promise methods from literature are shortly analyzed for applicability at GEP.

Ad 1. The first lead time method is a fixed lead time. Because orders are not rejected by GE Plastics, it is difficult to promise a short fixed lead time. After all, capacity adaptation is a long term decision, so in the case of a higher order load, lead times get longer. The demand is considered as unstable, so variation in order load is expected. As explained in section 5.1.2, the lead time syndrome can cause this unstable demand. However, it is known that a quarterly periodic effect is encountered in demand as well.

It is recommended to investigate the impact of the lead time syndrome as future research for GE Plastics. Completely fixed lead times assumes the decision to reject orders, something that GE Plastics is currently avoiding. Selçuk et al (2006[2]) showed that at a low degree of variability lead time update provides better cost than at a high degree. However, the option of fixed lead times will not be included in this research, because first more insight is needed in the impact of the lead time syndrome.

Ad 2. The second lead time method is variable lead times based on aggregate information. In a previous Master research by Govers (2006) that is conducted at GE Plastics, a good proposal is made on how the lead time can be determined at an aggregate level by use of the load profile. This will not be repeated in this thesis, so for more information on this proposal for order acceptance based on the aggregate level, the reader is referred to her master thesis.

Ad 3. The third and last lead time method is variable lead times based on detailed schedule information. The current order acceptance function still uses the detailed schedule information. However, a new ERP system is currently being implemented at GE Plastics, where the lead time will be determined based on an aggregate level. During the next years this implementation is done in phases, so until complete implementation, the old system is used to determine the lead time. Because the current order acceptance function will still be used in the near future, a solution is needed to improve the accuracy of this lead time method. Therefore the next section will discuss the possibility to improve the current lead time promise.

5.3 Improve lead time promise logic

It has been concluded that one of the most important root causes for incorrect production alignment is the lack of scheduling margin (3.6). This lack of rescheduling margin is a result of the first manufacturing promise logic (appendix J). The first manufacturing promise is the due date based on the lead time promise. In order to create a rescheduling margin for every PO, this first manufacturing promise logic must be changed. This new logic is presented in figure 5-4.

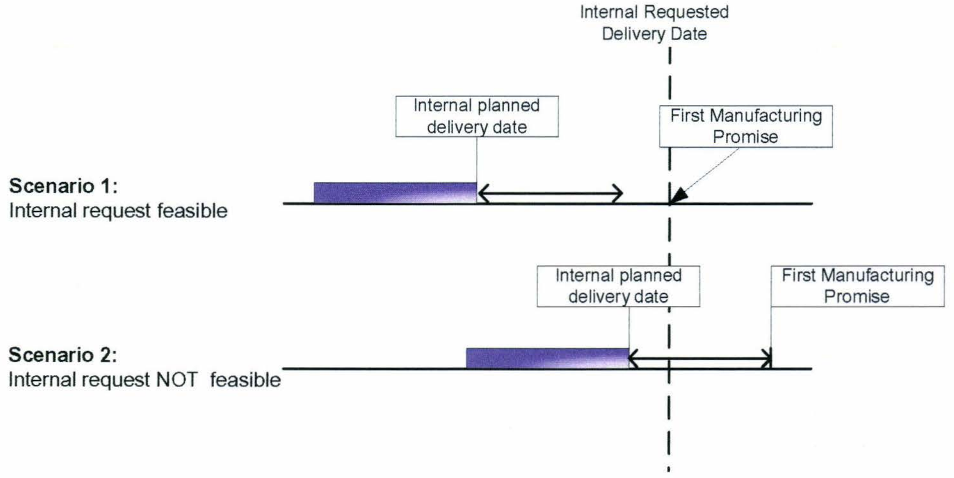

Figure 5-4: Improved first manufacturing promise logic

In the old logic, the order of scenario 2 would get a first manufacturing promise equal to the internal requested delivery date. Therefore, the order had less rescheduling margin than standard. Now in the new logic, also this order gets its standard rescheduling margin. This rescheduling margin is necessary to absorb various sources of variation.

Based on analysis of incorrect production alignment it is expected that this new logic will increase the delivery to first manufacturing promise. Together with the improved extrusion lead time, it is expected that the target of 90% accuracy can be achieved. Other suggestions for improvements within the current planning structure are given in appendix V.

5.4 Analysis of future ERP lead time promise

GE Plastics is currently implementing a new ERP system, Oracle 11i, which will take over a part of the hierarchical production control structure. First plant where the ERP software will be implemented is the Noryl plant in Bergen op Zoom, with a planned start in October 2007. The implementation of this ERP system will change the hierarchical production control structure to the situation presented in figure 5-5. This shows that the lead time decision will indeed be based on a tactical aggregate level, using available to promise (ATP).

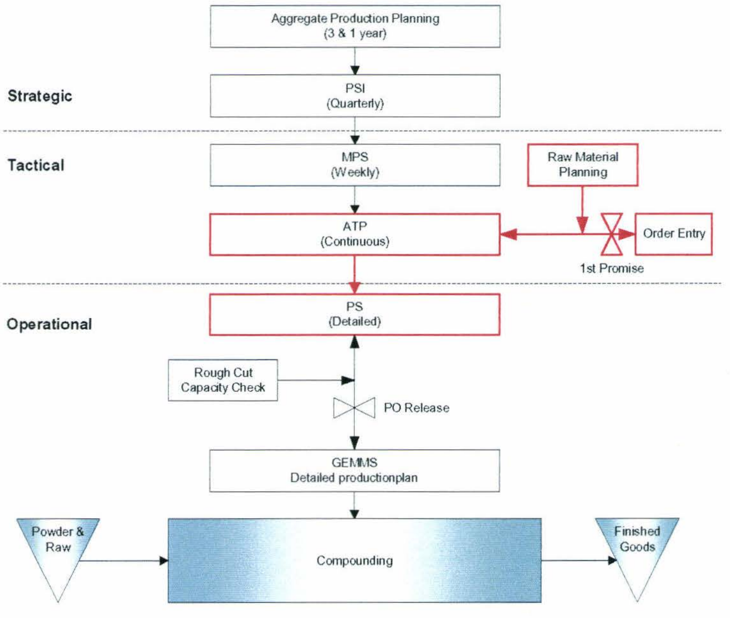

Figure 5-5: New Oracle 11i production planning structure

Furthermore PS will replace PSP. Because the order acceptance function is taken over by ATP, PS will focus on scheduling based on the due date, created in ATP. ATP will get its information from PS about the status of the production system. Based on that status, a lead time promise is given to the customer.

It is expected that the new ERP system will solve the three shortcomings of PSP. The lead time promise is not based upon the detailed schedule construction anymore, but on aggregate information. Therefore human intervention is not needed anymore and the lead time can virtually be promised in a split second. Also the new procedure for planning the first manufacturing promise always on target earliness can be implemented in the new ERP system. Notice that using aggregate information solves all these shortcomings.

However, once the first manufacturing promise is determined, PS must schedule the order in such a way that it will not become late. The main difference between PS and PSP is that PS is expected to be much more flexible in optimizing and adjusting the schedule. One of the major drawbacks of PSP was that it used slot scheduling. PS is able to optimize a certain time frame, taking into account all free capacity. Furthermore it is expected that PS can optimize the sequence based on due dates and minimum changeovers.

The fact that PS does also optimize on due date is new. The plant is currently only used to optimize on changeovers. Optimization based on due date will cause less optimal changeover sequence. The resistance for optimizing on due date should not be underestimated. The plant is currently accounted for maximum output given the frozen schedule. The plant itself, however, currently makes the frozen schedule and therefore optimizes the sequence for maximum output, based on changeovers. Without adjusting the performance measures, conflicting situations will occur, because of contradictory interests.

In the next section the analysis will be extended to the drivers for Δ2 production alignment performance.

5.4.1 Impact on Δ2 production alignment

For the impact on drivers for Δ2 production alignment, this section only discusses the drivers for which a change is expected prior to the enhanced lead time method.

The first late, *sequence optimization*, was already partially solved by creating more margin. In the new situation, the first manufacturing promise is not based on the detailed schedule anymore. Therefore PS must schedule the order within the restricted due date given based on the aggregate information.

In PSP the sequence is only optimized for the next frozen period. One of the reasons why this optimization is not done for a longer time period is because PSP does not bring up a desired sequence. Despite all expectations, PS will use the same data structure for sequencing as PSP does. The only enhancement will be based on due date violation. So without reviewing and updating the data structure, a better result is not expected regarding sequence optimization. Another function that PSP lacks is the ability to optimize over several production lines. Therefore line changes could only be done by human intervention. It is the objective that PS will be able to sequence across lines, but by all knowledge of the author this thesis, this is not yet achieved.

A part of the fifth late, *execution line delay,* was caused by incorrect production planning parameters. In was shown in chapter 4.1.2 that a minimum production quantity was needed due to the difference between the PO and the actual production quantity. The ERP system will schedule a production order that includes this minimum production quantity. Therefore it is expected that the accuracy of the production lead time will increase. Now the prediction model can simply be optimized based only on average run rate. But remember that the average run rate is not equal to the run rate corresponding to the average run time.

However, execution line delay is currently moreover caused by other factors. Therefore, in example, it is important to reduce the variance in changeover and run times and remakes, in order to further reduce the impact of execution line delay.

The seventh late and fourth early, *time difference RDD change,* is completely eliminated by the new ERP system. Determining the lead time promise for a changing order is based on up to date aggregate data.

The third early, *slot scheduling,* is completely eliminated as well. PS is much more flexible in scheduling capacity on the line, because it considers all free capacity and is able to move around orders. Of course the basic principle is that the due date is not violated.

Tables 5-1 and 5-2 evaluate the impact of the new ERP system on the drivers for Δ2 production alignment performance.

Table 5-1: Impact of improved lead time method on drivers Δ2 production alignment

	Δ2 Late	Solved for new ERP	Remarks
1	• Sequence optimization	Partially +	
2	• FCFS overruled	Partially	Commercial decision
3	• System bug weekend	Yes	
4	• Time difference first promise	Yes	
5	• Execution line delay	Partially	
6	• Reallocated from other plant	No	Often due to superior powers
7	• Time difference RDD change	Yes	

Table 5-2: Impact of improved lead time method on drivers Δ2 production alignment

	Δ2 Early	Solved for new ERP	Remarks
1	• Low order load	No	Commercial decision
2	• Target earliness	No	Commercial decision
3	• Slot scheduling	Yes	
4	• Time difference RDD change	Yes	
5	• Sequence optimization	Partially +	
6	• FCFS overruled	No	Commercial decision
7	• Time difference first promise	Yes	

5.5 Conclusions

GEP does not reject orders. With that strategy, purely fixed lead times are expected to be infeasible, given the unstable demand. However, it is recommended to investigate the lead time effect of the current lead time promise on this unstable demand (5.2).

A new lead time promise logic is presented, which promises a lead time based on a fixed rescheduling margin. It is expected that this new logic will increase the delivery to first manufacturing promise. Together with the improved extrusion lead time, it is expected that the target of 90% accuracy can be achieved.

A new ERP system will be implemented in the near future. It has been concluded that the production planning structure of this ERP system will eliminate most of the current issues with production alignment. Furthermore, the lead time promise will be based on aggregate information. Therefore, issues concerning lead time promise based on detailed scheduling, will be eliminated.

The new ERP system will not solve the sequencing issue, because the same data structure will be used. Furthermore, the new sequencing algorithm will also include due date violation. The resistance from the plant regarding sequencing on due date violations must not be underestimated, because of conflicting targets. After all, the plant is measured on produced quantity and a sequence based on due date violation is less optimal then on changeover time.

6 Conclusions and recommendations

On time delivery performance is becoming an increasingly important driver to achieve competitive advantage for GEP. Therefore it is important for manufacturing to be reliable in delivery to first manufacturing promise, what equal to lead time promise in literature. In order to become reliable, it is necessary to know what the originators are for unreliability. Because in the recent past, the focus of GEP was on delivery to request, very little is known about the causes for unreliability with respect to delivery to first manufacturing promise.

Therefore the first part of this report investigated the root causes for an unreliable delivery to first manufacturing promise (chapter 3). Based on the results from the first part, the reliability is improved in the second part of this report. Therefore the prediction model for extruder throughput time is redesigned (chapter 4) and adjustments are made in the design of the first manufacturing promise procedure (chapter 5).

Conclusions and recommendations are given in this chapter. First the conclusions resulting form the analysis on the unreliability are discussed (6.1.1); second the conclusions from the redesign of the prediction model and the adjustments in the manufacturing promise procedure are summarized (6.1.2). The chapter ends with recommendations (6.2).

6.1 Conclusions

6.1.1 Conclusions from analysis phase

The manufacturing order to delivery process is divided in three separate parts:
Δ 1; from order entry until first manufacturing promise creation; state "New"
Δ 2; from first manufacturing promise creation until order release (production alignment); state "Planned"
Δ 3; from order release until finish production (production execution); state "Released"

Only Δ2 and Δ3 have impact on delivery to first manufacturing promise, because in Δ 1, no promise is determined yet. With respect to delivery to first manufacturing promise performance it can be concluded that:

1. Δ2 production alignment has the largest impact on delivery to first manufacturing promise. This involves all SO that are scheduled, but not yet released for production.

2. Almost half of the orders that were planned late on the moment of order release are finally finished before the first manufacturing promise. This indicates that many unnecessary adjustments of the promised delivery date are generated.

Regarding the analysis on drivers and root causes for production alignment performance it can be concluded that:

3. Most of the root causes are directly or indirectly related to the inflexibility of PSP. This inflexibility can be denoted by slot scheduling, incorrect sequencing and (lack of) rescheduling margin.

4. Prediction of extruder lead time is not in line with reality. However, the capacity loading is based on this extruder lead time prediction, which is the detailed schedule. The first manufacturing promise is based on this capacity loading. Therefore, the incorrect extruder lead time causes an incorrect first manufacturing promise.

6.1.2 Conclusions from design phase

From the design phase it was already concluded that correct extruder lead time prediction is important. In chapter 4 the prediction model is discussed. Main findings of this chapter are:

5. Lead time prediction can be improved by less variation in the process. Although this is not the research topic, it has been concluded from analysis that the changeover times have a large opportunity for variation reduction.

Three prediction models are analyzed;

- The enhanced model schedules exactly on the mean
- The current model represents the initial situation
- The optimized current uses the current model, but optimizes its parameters

6. In the current model, changeover times are not maintained and controlled, even though the model is capable of it. Furthermore the current model does not account a minimum production quantity. The used procedure to compensate this imbalance is incorrect.

7. In the optimized current model the changeovers are maintained and the parameters are optimized. In the enhanced model, the minimum production quantity is explicitly used for calculating the extrusion lead time. However, because the changeover times have a much larger variance, both models perform comparable.

8. Slack time in the schedule is used for dealing with sources of variation in the production process. Besides variance in extruder throughput time, this also involves remakes and insertions. However, for the investigated extruder, only the current variance in extruder throughput time causes a need for slack of 19 with 95% reliability. So to deal with remakes and insertions as well, even more slack is needed.

Finally chapter 5 discussed other improvements related to the first manufacturing promise. From this chapter can be concluded:

9. A new lead time promise logic is presented, which promises a lead time based on a fixed rescheduling margin. It is expected that this new logic will increase the delivery to first manufacturing promise.

10. A new ERP system will be implemented in the near future. It has been concluded that the production planning structure of this ERP system will eliminate most of the current issues with production alignment. Furthermore, the lead time promise will be based on aggregate information. Therefore, issues concerning lead time promise based on detailed scheduling, will be eliminated.

11. The new ERP system will not solve the sequencing issue, because the same data structure will be used. Furthermore, the new sequencing algorithm will also include due date violation. The resistance from the plant regarding sequencing on due date violations must not be underestimated, because of conflicting targets. After all, the plant is measured on produced quantity and a sequence based on due date violation is less optimal then on changeover time.

6.2 Recommendations

Recommendations are sorted on recommendations based on this research and recommendations for future research. First the recommendations based on this research are discussed.

1. Decouple the readjusting promise process from the detailed schedule.
2. Keep track on reasons for due date violations proactively
3. Redefine the data structure for changeover optimization
4. Focus on reduction of changeover time

Based on the analysis of impact of production alignment and production execution it is recommended to decouple the adjustments in promised delivery dates from the schedule. It was shown that in almost half of the cases where production alignment was late, the order was finally produced on time. Therefore it is recommended to only adjust the promised delivery date when the first manufacturing promise is actually violated. So only when the current date is later than the first manufacturing promise, the promised delivery date should be adjusted.

Keep track on reasons for due date violations proactively, because finding the core driver for the due date violation afterwards is not accurate. This is difficult because a PO is often delayed by more than one factor and often by indirect factors instead of by direct factors. In this context, a direct factor is directly related to the order, whereas an indirect factor is directly related to another order.

Redefine the data structure for changeover optimization. Govers (2006) proposed a good concept for changeover sequence determination. However, in practice the concept does not seem to work, as the sequencing based on changeovers is still not automated. Therefore it is recommended to conduct research on possibilities to redefine this concept. This can for instance be done based on standard cycles from light to dark. This can be combined with a possible lead time promise.

Focus on reduction of mean and variance for changeover times. The percentage changeover time is very high compared with the run time, so much can be gained by changeover time reduction. Reduce the variance in changeover time in order to become more predictable. Reduce the mean in changeover time in order to create more production capacity.

Then finally the following recommendations for future research are suggested:

1. Investigate impact of the lead time syndrome on the demand
2. Investigate impact of remakes and insertions on the delivery to first manufacturing promise
3. Cost benefit tradeoff between plant utilization and stock building
4. Redefine changeover optimization, possibly together with lead time promise strategy

The first recommendation for future research is to analyze the impact of the lead time syndrome on demand for GE Plastics. GE Plastics suffers from unstable demand, clearly not only caused by the lead time syndrome. However, understanding the impact of lead time syndrome can help GE Plastics in optimizing the lead time strategy. This might be a very interesting research topic, since currently no robust adaptive lead time strategy is known.

Another recommendation for future research is the impact of remakes and insertions on the delivery to first manufacturing promise. Because delivery to first manufacturing promise is just started up, no quantitative insight is known on this impact. However, the impact is important to determine how much slack and/or earliness margin is needed. The research will help GE

Plastics improving the accuracy of the first promise. A more accurate first promise will need less margin earliness for rescheduling, so lead time can be reduced.

The third recommendation for future research is a cost benefit tradeoff between plant utilization and stock building. Stock is negative for cash flow and therefore should be minimized, with the restriction that a certain service level is assured. Currently, in the case of low demand, MTI products are produced to reach the production targets. Question is whether it is economically wise to build stock just to commit to the production targets.

The fourth and last recommendation for future research is the redefinition of the changeover optimization. It is concluded that the current data structure does not work optimal in practice. Sequencing in a fixed cyclic pattern can be a possible solution, and based on this cycle a promise can be generated. However, first research must be conducted whether this is indeed possible for GE Plastics.

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Website

www.ge.com Last read on 29-07-2007

Abbreviations

ADD	Actual Delivery Date
ATP	Available to Promise
aTTFG	Actual Transfer To Finished Goods; Manufacturing ready
COT	Changeover Time
cTTFG	Calculated Transfer To Finished Goods; Manufacturing derivation from RDD
ERP	Enterprise Resource Planning
FCFS	First Come First Schedule; Scheduling priority rule
GEP	General Electric Plastics
LC	Logistics Centre; Location from where warehousing and distribution is done
MPQ	Minimum Production Quantity
MPS	Master Production Schedule; Tactical planning which translates the PSI into week
MTI	Make To Inventory
MTO	Make To Order
NPS	Net Promoter Score, a continues survey used by GE to measure customer satisfaction
OED	Order Entry Date
OPT	Optimized, used as scenario for the prediction model
OTD	Order To Delivery; The process from order entry to delivery to the customer, with respect to time
PDD	Promised / Planned Delivery Date
PO	Production Order; Order number used by Production
PS	Scheduling software; successor of PSP
PSP	Production Scheduling Process; Scheduling software used by Material Management to schedule production orders on extruders
PSI	Production Sales Inventory; Aggregate planning consisting of sales targets
pTTFG	Planned Transfer To Finished Goods; Manufacturing planned to be ready
RDD	Requested Delivery Date; requested by the customer
RR	Run Rate
RT	Run Time
SO	Sales Order; Order number used by Sales
TTFG	Transfer To Finished Goods; Moment that manufacturing delivers a PO to Material Management

Appendices

A. MTI Guidelines

GEP Procedure for definition of MTI products. Last read on 12-01-2007.

OBJECTIVE:
- What are the criteria to make an item MTI or MTO?
- How are the safety levels, runsizes, etc calculated

SCOPE:
Material Management Fulfillment and Import/Export

DEFINITIONS:

MTI:	Made-To-Inventory
MTO:	Made-To-Order
BO:	Business Objects
SS:	Safety Stock
CAM:	Centralized Admin Module
VMI:	Vendor Managed Inventory
Demand:	Volume requested by customer for a fiscal month (based on requested week). It is a combination of sales (invoices) and order (backorders, not yet invoiced) volumes
Stability:	s/m (standard deviation / mean) based on month-to-month demand volumes

CHANGE:
On page 2 what to do (MTI or MTO) with an item, when the "score = 4 and the criterium 2 or 5 = 0", has been changed. It is now either a D (in case of LST) or a C and not anymore "D or C-item, chase for forecast". The procedure Changes In Item ABCD Coding has been added below as an associated document.

PROCEDURE:
The decision process on what to make an MTI item and where to stock them is driven by the MTI Standard Stock Items Selection Process and/or commercial teams

Note: the actions in this procedure need to be reviewed at least every 2 months

<u>Item Selection</u>

Items are selected for MTI Standard Stock based on 5 criteria/attributes:
Criterion 1: Average monthly volume for last 4 months >= 2,500 kgs for resins, >= 1,000 kgs for SF&S and >=750 kgs for imports
Criterion 2: Number of customers for items > 3 over last 3 months
Criterion 3: Stability of month-to-month demand over last 12 months s/m(12) <= 1.0
Criterion 4: Stability of month-to-month demand over last 4 months s/m(4) <= 1.0
Criterion 5: No dominant customer (>75% of volume in any month)

For the MTI/MTO selection the following BO queries are used:
Y:\Supply Chain Management\Material Management\FulfillmentTeam\MTI selection\Item Stability8.rep (for criterion 1, 3 & 4)
Y:\Supply Chain Management\Material Management\FulfillmentTeam\MTI selection\ MTI Selection Tool # Cust last 3 months .rep (for criterion 2 and 5)

These BO queries are combined in an Excel-file, that determines the score on these 5 criteria. The steps to create this Excel-file can be found in the Appendix A at the end of this procedure.

Depending on the score, an item is made MTI (A or D) or MTO (C):

Score = 5	A-Item
Score = 4	if criterium 1 or 3 = 0 then A-item if criterium 4 = 0 then A of C-item by checking criterium 3

	if criterium 2 or 5 = 0 LST then D-item, otherwise C-item
Score = 3	if criterium 1, 3 = 0 then A-item, LST then D-item, otherwise C-item
Score = 2	D-item for LST or Growth reasons
Score = 1	D-item for LST or Growth reasons

<u>Determining Frequency of Replenishment (under revision)</u>

The replenishment period for selected standard stock items is largely driven by mean volume. The following rules are applied to determine the replenishment period for standard stock items. The monthly volume used in the rules is the average monthly demand for the last 4 months m(4).

The checks are performed in the order below:

Check 1. Replenish weekly (Period = 1)
m(4) >= 40,000 Kg - or - m(4) >= 20,000 Kg and no dominant customer

Check 2. Replenish bi-weekly (Period = 2)
m(4) >= 20,000 Kg and dominant customer - or - m(4) > 5,000 Kg

Check 3. Replenish monthly (Period = 4)
By default, if checks 1 and 2 fail, then the item is replenished monthly.

<u>Setting the Inventory Levels (under revision)</u>

- Runsize
The run size is only changed after item-selection has been concluded (see procedure CAM: Modify An Item ABCD Code).
The run size is based on the monthly demand divided by the interval of replenishment.
It is rounded up to full containers for all standard packaging types.

If period is 1 (weekly), run size = m(4)/4,
If period is 2 (bi-weekly), run size = m(4)/2
If period is 4 (monthly), run size = m(4)

- Safety stock
The safety stock (minimum stock Level) is only changed after item-selection is concluded (see procedure MTI Maintenance SS Levels).

To calculate the safety stock the following BO query is used:
Y:\Supply Chain Management\Material Management\FulfillmentTeam\MTI selection\Safety Stock.rep)

The minimum stock level in this BO query is calculated as followed:
= If <Percentage of Weeks Above 3xMean*> >= <Allowed Percentage Wks Above Mean**> Then 2*<Mean Wkly Qty*> + <Adj Std Dev Qty> Else If <Percentage of Weeks Above 2xMean> >= <Allowed Percentage Wks Above Mean> Then <Mean Wkly Qty> + <Adj Std Dev Qty> Else <Mean Wkly Qty>

* Mean/ Mean Wkly Qty: Mean of selected period in wks
** Allowed Percentage Wks Above Mean: currently set at 10%

Non real MTI process:
Non real MTI's have a Safety Stock level of 0 on the plant warehouse, and can be flagged in Manugistics, so they do not appear as stock-outs in the stock-out measurement.

Examples of Non real MTI items are:
System MTI (D-item with SS=0 in plant warehouse, e.g. Platform- or VMI-items)
Workout MTI (MTO-item set-up as MTI to be able to use Manugistics efficiently)

Technical MTI (MTO-item set-up as MTI to always have a runsize according to the minimum technical plant capability)

See process at the end of this procedure.

ASSOCIATED DOCUMENTS

MTI Maintenance SS Levels
CAM: Modify An Item ABCD Code
Changes In Item ABCD Coding
Steps to do to create the Excel-file, that determines the score on the 5 criteria :

Adjust the following conditions in the BO query "Item Stability8.rep" by clicking the "Edit Data Provider"-icon:
fill in productgroup the MTO/MTI selection needs to be done for
change the dates; start last year (12 months back) end last month (1 month back)
Run/refresh query
Edit → Copy All

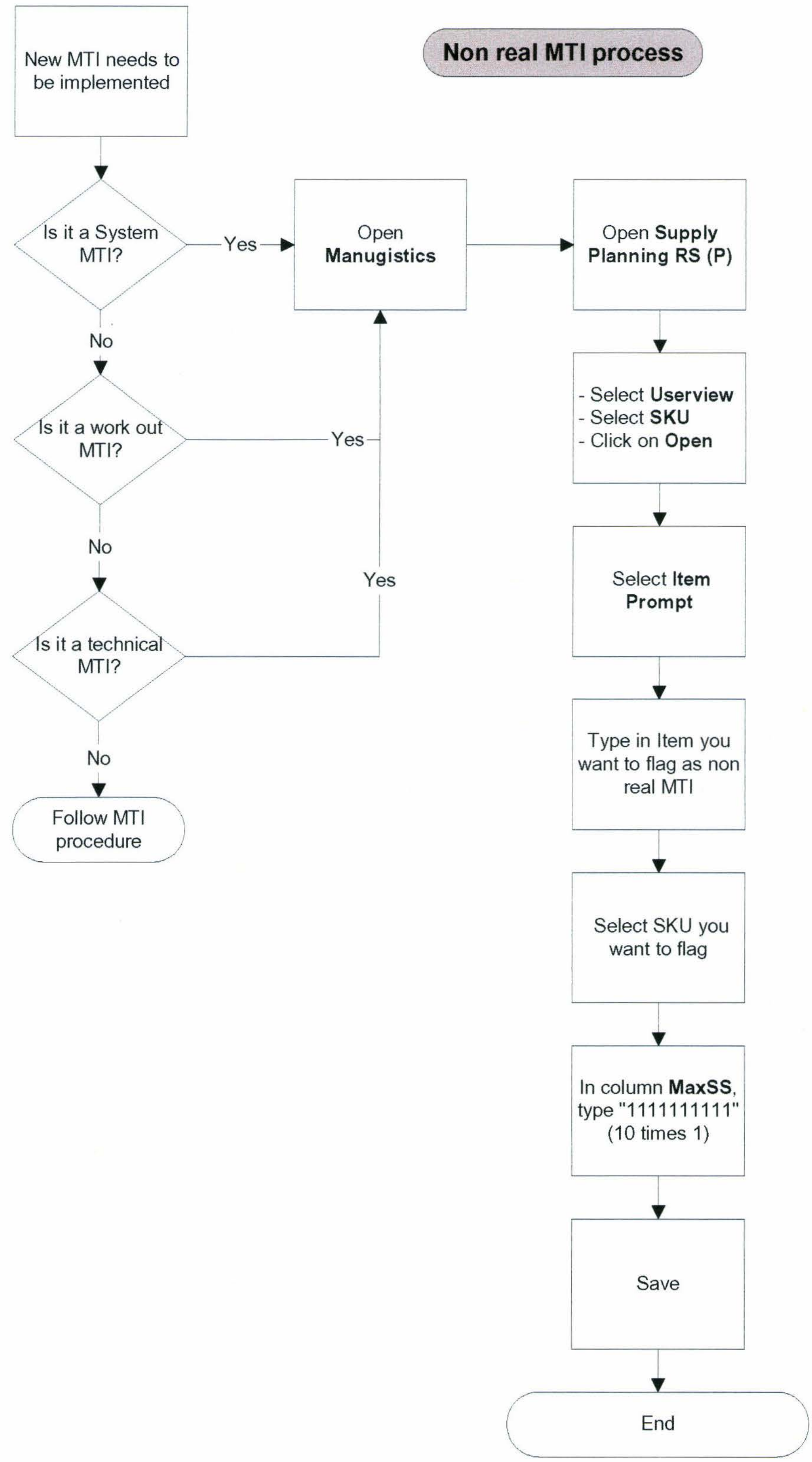
Adjust the following conditions in the BO query "MTI Selection Tool # Cust last 3 months .rep" by clicking the "Edit Data Provider"-icon:
Requested date exactly 12 months back
fill in product group in division code
Run/refresh query
Edit → Copy All

Open in Excel the file "MTI MTO selection template" (on datshare Y:\Supply Chain Management\Material Management\FulfillmentTeam\MTI selection)
Copy Paste the "Itemstability8" BO data in worksheet "paste stability"
Copy Paste the "MTI selection tool #cust last three months" BO data in worksheet "paste customer info"
Copy column E thru P (in worksheet "example") by selecting the columns
Insert copied columns in column E on worksheet "paste stability" by clicking on column E and right-click mouse
In cell I3 construct "vlookup" function that looks for "dominant customer" in the worksheet "paste customer info". Copy throughout column I
In cell J3 construct "vlookup" function that looks for "# customers" in the worksheet "paste customer info". Copy throughout column J
Save the file under MTI folder "MTI selection "product group"-"data"

System MTI:
D item with SS=0 in plant warehouse

Workout MTI:
MTO item that is set up as MTI to be able to use Manugistics efficiently

With technical MTI is meant here, a technical MTI-item with SS=0 in plant warehouse



B. Explanation NPS Survey

In the NPS survey customers are asked to give a rating on a scale from 0 to 10 on five different sub categories, being Support after Sales, Delivery, Innovation, Quality and Ease of doing Business. Based on this score, customers are divided in three groups, being detractors, passively satisfied and promoters.

- Customers that give a rating of 6 and below are referred to as **detractors**. These customers are extremely unlikely to recommend you to a friend or colleague. They destroy value by telling people they know how bad you are performing. Building stronger relationships with detractors, particularly detractors within your strategic customer base, is critical to any business.
- Customers giving a rating of 7 or 8 are referred to as **passively satisfied**. Although they might not be speaking poorly about you to their friends and colleagues, they are also not likely to recommend you either. These customers are at risk – they are likely to jump ship if a better value proposition comes along.
- Customers giving a rating of 9 or 10 are referred to as **promoters**. These customers are the most likely to tell their friends and colleagues how good you are. Customers in this category show the strongest repurchase and referral rates. You should consider them as an extension of your marketing and sales team.

Finally a score is calculated where the percentage of detractors is subtracted from the percentage promoters. This relative score is used for benchmarking with other NPS scores. First of all it is used to compare the different sub categories with each other, to determine on which subcategory should be the main focus for improvement. Second of all it is used to compare with other businesses that use NPS as well, to determine how well GEP performs compared with those businesses.

Figure B-1: Example of NPS score on delivery and quality

C. Lead Time Promise cycle

The lead time promise is generated based on the detailed extrusion schedule. The lead time promise can consist of distribution lead time and manufacturing lead time. The distribution lead time consists of transportation time and one day warehouse handling. For the distribution lead time, a fixed number of days is determined depending on the destination and transport mode.

For MTO products the lead time will always consist of manufacturing and distribution lead time. This manufacturing lead time is a result of the detailed extrusion schedule. The lead time promise is connected with so called timestamps. These timestamps are dates that are important for a PO or SO. Figure C-1 shows an example with timestamps that are important for this research. This is an example of a MTO product. Because it is a MTO product, the PO and SO are linked to each other. In the case of a MTI product, the blue bars can be ignored, because it is assumed that the product is on stock.

The example shows four steps in which the different timestamps are created. The four steps are explained in more detail below, but it is important to know that the different steps are all representing the same SO. The white boxes represent the timestamps.

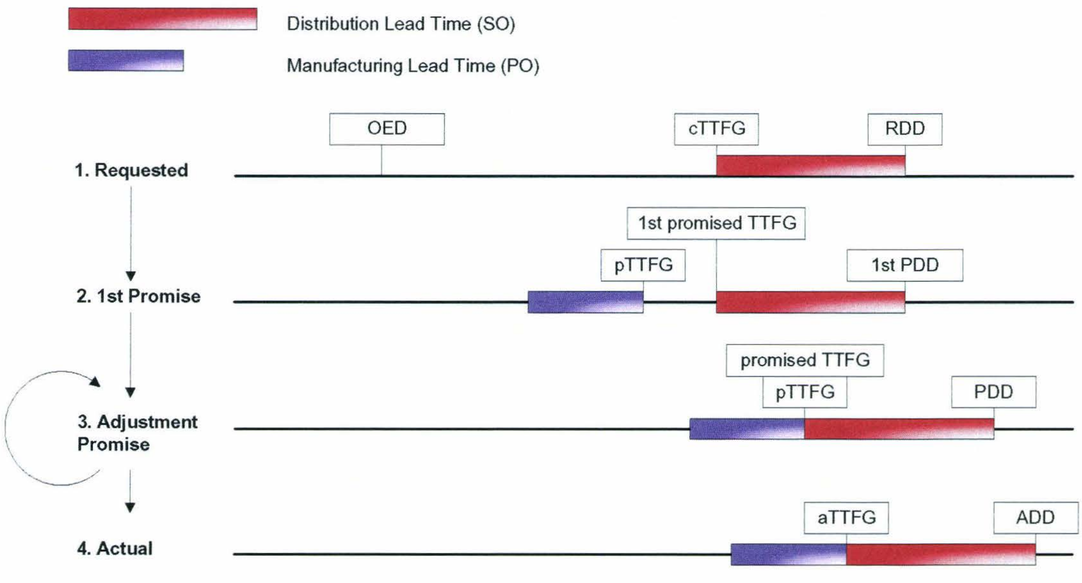


Figure C-1: Timestamps for a MTO order

The first step is the request of the customer. On a certain date an order is entered (OED) with a Requested Delivery Date (RDD). Based on the distribution lead-time (red rectangle) an internal requested delivery date is calculated for manufacturing called the calculated Transfer To Finished Goods (cTTFG). This is the latest day that Manufacturing should finish production to be able to deliver the goods as requested by the customer.

The second step is the 1^{st} promise to the customer. Before this first promise can be generated, the order must be scheduled on a production line (blue rectangle). After that the order is scheduled, it is evaluated if it is possible to deliver on RDD. In the example above this is possible, so the first promised delivery date (1^{st} PDD) is equal to the RDD. The 1^{st} promised TTFG is the latest allowable due date for manufacturing. However, the actual scheduled due date is equal to the timestamp pTTFG.

The third step can happen multiple times on an order after the first promise is given, because the production schedule is adjusted every day. When the production schedule is adjusted it is possible that an order is planned for production later, so the pTTFG will be later as well. This is illustrated in step three of the example above. Here the pTTFG is changed to a date later then the 1st promised TTFG and therefore the promised TTFG will be adjusted to the new pTTFG. Because the PDD is based on the pTTFG and the distribution lead-time, the PDD will change as well, causing an adjusted promise. This step also shows that the timestamps promised TTFG, pTTFG and PDD can change, unlike the other timestamps, which are fixed after determination.

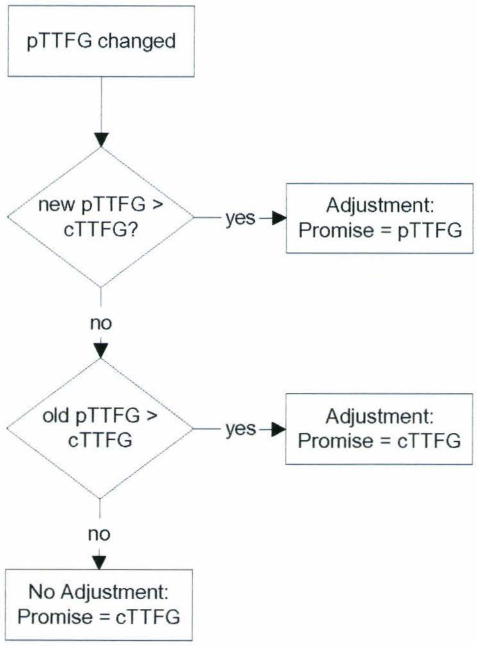
Finally, the fourth step is the actual performance. So aTTFG is the actual internal delivery and the ADD is the actual delivery at the customer.

D. Responsibilities different departments

	Customer	Fulfillment	Customer Service	Scheduling	Production Plant	Supply Chain
States						
New	**x**	**x**	**x**	**x**		
Planned				**x**	**x**	
Frozen				**x**	**x**	
Finished					**x**	**x**
Activities						
Order Entry	x	x	x			
First Mfg Promise creation				x	x	
Order Release (Frozen Window)				x	x	
Actual Delivery LC					x	x
Timestamps						
cTTFG	x	x	x			
1st Mfg P				x		
frozen pTTFG				x	x	
aTTFG					x	
Span						
1st Mfg P - cTTFG	x	x	x	x		
PAF (frozen pTTFG - 1st Mfg P)				x	x	
PEF (1st Mfg P - aTTFG)					x	

E. PDD adjustment logic

pTTFG = internal planned delivery date
cTTFG = internal requested delivery date
Promise = Manufacturing promise (and therefore a customer promise)



F. PSP-Scheduling cycle

The PSP-Scheduling cycle shown in figure F-1 is a process that is manually executed once a day, from Monday until Friday. PSP is used as operational production planning tool. A Gantt chart presents the production planning visual on screen. The part of the production process that is scheduled in detail is extrusion, which is considered as the bottleneck for the compounding plants. The current scheduling window for the Lexan plant is eight weeks.

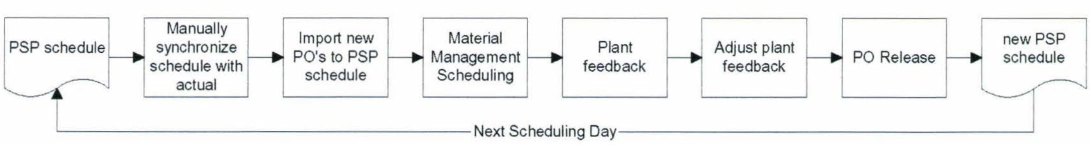


Figure F-1: PSP scheduling cycle

The PSP-Scheduling process starts with manually updating PSP to reflect the actual progress on extrusion lines. So for example when a line produced faster then planned, all released orders will be rescheduled to an earlier start.

The second step is to import new PO's to the schedule. These new PO's are being assigned to a line and given a place on that line automatically. Then the third step is the Material Management Scheduling, named after the Material Management department. In this step the scheduler will adjust the schedule based on own experience, allocation rules, guidelines and plant information. The basic adjustments that are done are change between plant, change between production line and change in production sequence.

After the Material Management Scheduling step, the plant is given the opportunity to provide feedback on the schedule. In general, the plant only gives feedback when a new frozen period is proposed. This 'four-days-frozen-schedule' is made twice a week on Monday and Thursday. Most of the time, the plant only uses a time window of maximum a week ahead. The plant feedback is a result of a material availability check, a rough capacity check and a sequence optimization. The plant also determines which PO's are accepted for the next 'four-days-frozen-schedule'.

Step five of the PSP-Scheduling process is to adjust the plant feedback in the schedule in PSP. The sixth step is to release orders for production. Only orders that are scheduled within the frozen period are released. On the moment of order release, the timestamp 'frozen pTTFG' is created.

The final result is the new PSP schedule, which will be the starting point for the next PSP-Scheduling cycle. When the final result is created, the first manufacturing promise is determined for all new PO's. The logic for the first manufacturing promise and the corresponding first promise to the customer is given in the next section.

When the final result is created, also the different states are changed. All PO's that received a first manufacturing promise are updated to state 'Planned' when they are not yet release for production. All the PO's that are released for production in step six are updated to state 'Frozen'.

G. Measurement tool for analysis phase

The first promised delivery date is captured by GEP in a database. The first manufacturing promise on the other hand, is not captured. A measurement tool is developed to capture the first manufacturing promise. For the measurement tool, the following formula is used to determine the first manufacturing promise.

$$\text{first Mfg P} = \text{MAX}(1^{st}\ \text{pTTFG};\ \text{cTTFG})$$

The second date that is needed for the measurement tool is the 'frozen pTTFG', which is directly linked to the order release. This date is already collected per PO. With these two dates available it is possible to measure the contribution to delivery to first promise of production alignment.

Besides the performance, also the drivers for incorrect performance need to be captured. For this a tool is developed in access (figure G-1), which measures every change in the rolling pTTFG. This is done, based on the listrun (schedule), provided by the Scheduling Team. Then for every change, a reason must be found for this change. The tool can be used for production alignment as well as production execution, but for this data analysis it is only used to get insight in production alignment. After all, production execution is already measured. Detailed findings of this part of the analysis are presented in appendices N to Q.

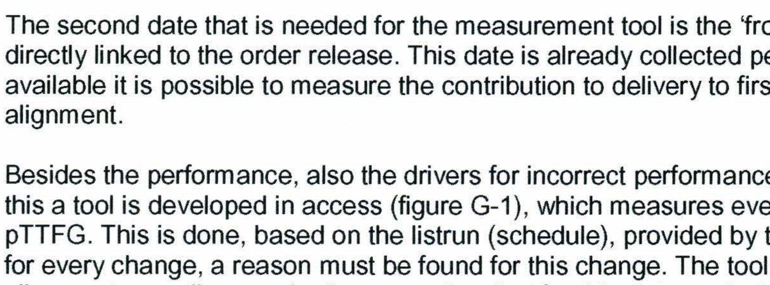


Figure G-1: Screenshot of MS Access measurement tool

H. Detailed results main originator analysis

Four months of data is collected for the Opaque flowstream, providing 760 PO's. This data is used to determine which of the two steps is the main originator to a bad performance on delivery to first manufacturing promise. A statistical analysis is conducted on this dataset to determine the correlation between the two steps and the performance on delivery to first manufacturing promise.

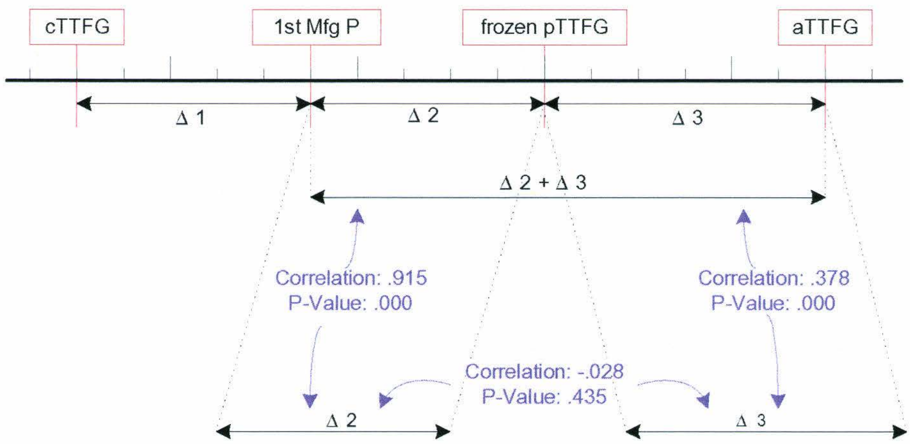


Figure H-1: Correlation analysis main originators

First analysis is a correlation analysis for the main originators Δ2 and Δ3 on the delivery to first manufacturing promise. The performance on delivery to first manufacturing promise can be measured by Δ2 + Δ3. Figure H-1 shows the result of this correlation analysis. It shows that there is no convincing evidence for a correlation between Δ2 and Δ3. There is significant evidence of a correlation between Δ2 and delivery to first manufacturing promise. The corresponding correlation factor is .915, indicating a very strong positive relationship. There is also significant evidence of a correlation between Δ3 and delivery to first manufacturing promise. The corresponding correlation factor is .378, indication a weak positive relationship.

Now that it is concluded that there is a correlation between delivery to first manufacturing promise on the one side and production alignment and production execution on the other side, the actual contribution must be determined. Because variation is the extent of control of a process, the two originators are compared in standard deviation. Table H-1 shows that the standard deviation of production alignment of 5.06 days is almost as large as the standard deviation of delivery to first manufacturing promise. Together with the fact that there is a very strong correlation, it is expected that production alignment is the main originator.

Table H-1: Standard deviation of different parts of the delivery to first manufacturing promise performance

Variable	Standard Deviation
Delivery to first manufacturing promise	5.47 Days
Δ2 Production alignment	5.06 Days
Δ3 Execution alignment	2.21 Days

Based on the correlation, a linear relation is assumed, so for both originators, a regression model is constructed. This analysis shows that Δ2 accounts for 83.6% of the variability of the delivery to first manufacturing promise. Δ3 on the other hand, accounts for 14.2% of the variability of the delivery to first manufacturing promise.

From a customer perspective, it is most important that an order is not delivered later than the promised delivery date. When a PO is finished earlier than the first manufacturing promise, the PO can be kept on stock, so the customer will not notice. On the other hand, when a PO is finished later than the first manufacturing promise, in general the customer is delivered later as well. Therefore an analysis is done, to determine the main originator of all PO's that were finished late. In total, 77 of the 760 PO's were finished later than the first manufacturing promise. From this 77 late PO's, 47 were already late at the moment of order release. So 61% of the late PO's are directly caused by Δ2 production alignment.

However, when on the moment of order release a PO is scheduled for TTFG later than the first manufacturing promise, the promised delivery date is adjusted. After the order release it is possible that production execution is done faster then planned. Therefore it is also important to know how much PO's are already late at the moment of order release. In total, 90 of the 760 PO's were planned late on the moment of order release, what will be defined as a **late released PO**.

A **late released PO** has a manufacturing promise on the moment of order release, which is later than the first manufacturing promise.

So at least 12% of all the PO's are late released PO's. Two analyses are done on these 90 late released PO's. The first is done from the *adjusted promise* perspective and the second is done from the *first manufacturing promise* perspective.

From the *adjusted promise* perspective it is necessary to know if the adjusted manufacturing promise is finally achieved by Δ3 production execution, because that will indicate if the adjusted promise was correct. From the 90 late released PO's, 74 were finished on or before the adjusted manufacturing promise, so 82% of the PO's are finished before the adjusted manufacturing promise

From the *first manufacturing promise* perspective, it would have been unnecessary to adjust the promise, when after all the first manufacturing promise is finally achieved. Therefore an analysis is done on how much late released PO's were finally finished on time with respect to the first manufacturing promise. From the 90 late released PO's, 43 PO's were finished on time with respect to the first manufacturing promise, what is equal to 48%. In words that means that at least 48% of the PO's where the promise was adjusted before order release, should not have been adjusted, because after all, the PO was finished before the first manufacturing promise.

I. Top 7 Results late and early release

In this section, a pareto analysis of late release drivers will be presented and explained. Subsection 0 summarizes the root causes for these drivers.

Figure I-1 shows the top seven drivers for late release, which will be discussed in this section. The complete representation of the pareto analysis of drivers for manufacturing late is presented in appendix N. The top seven drivers are responsible for 88% of all late releases.

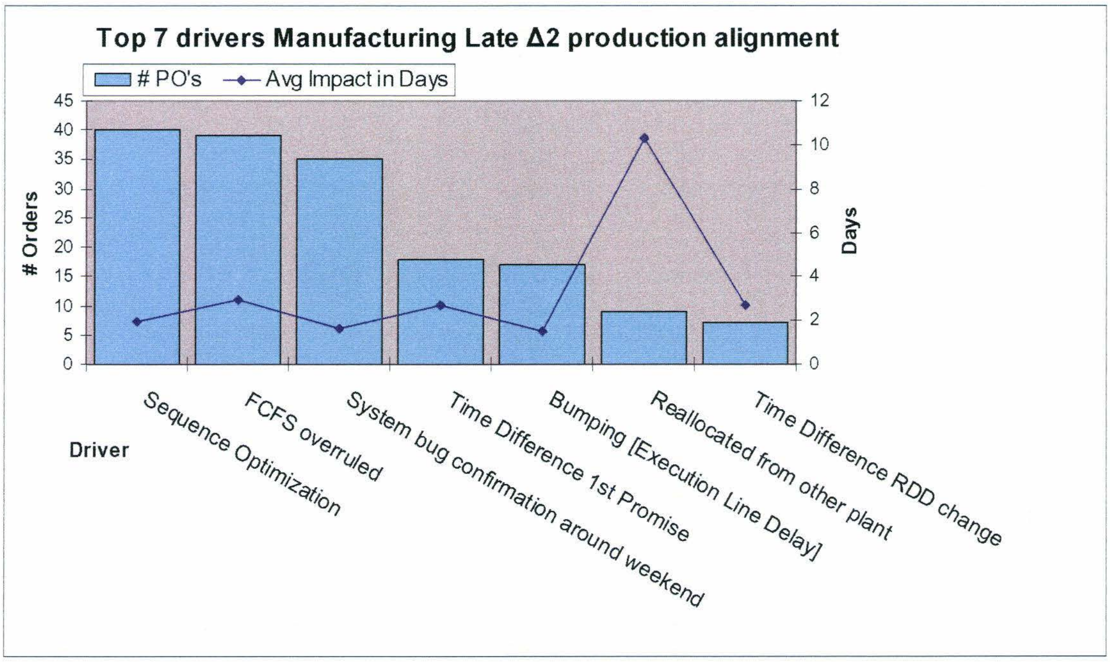


Figure I-1: Pareto Top 7 drivers late release

[L-1] Sequence optimization

The first and most occurred driver for late release is sequence optimization. This sequence optimization refers to the plant feedback of the PSP scheduling cycle (appendix F). The goal of sequencing is to minimize the cleaning time of a changeover. Sequencing is done twice a week, when a new frozen period is created. Initially it is tried to schedule orders on or before target earliness. The goal of the target earliness is to create a scheduling margin for processes like sequencing. Therefore, only orders that have a scheduling margin of less than the target earliness can become late released due to sequencing.

On the moment of order entry, the orders are not yet sequenced. Sequencing is only done manually for the next frozen period. PSP has an optional possibility for automated sequence optimization. However, the result of this automated sequence optimization is not considered as optimal by the plant. Because the automated sequencing is not considered functional, it is omitted.

There are two main differences between manual sequencing and PSP sequencing. Firstly, PSP sequencing is not capable of optimization across extruder lines. Secondly, PSP only uses the color code to sequence. The manual sequencing is done based on color and additives. Some additives are very hard to clean, but can not be traced via the color code. Therefore it is assumable that PSP is not generating an optimal sequence. PSP is able to sequence on both color and grade, but this functionality is currently not exploited for Lexan.

On the moment of order entry, the future state of the production system is not known yet. Hence, the future optimal sequence is not known as well. Based on this not optimal sequence, a first promise is generated. Therefore scheduling flexibility is created by initially planning on a target earliness. However, not every order gets this target earliness.

There are two root causes for this driver;

- Lack of scheduling margin (target earliness).
- Inability of PSP to optimize the sequence automatically.

Both issues raise the question why a first promise is generated based on a not optimal detailed schedule.

[L-2] FCFS overruled

New orders are scheduled following a First Come First Serve rule. So the order that is entered first has the right to be scheduled first. The second driver for late release is the overruling of this FCFS rule. Overruling can only be done manually. There are two main causes for overruling;

- Insertion process
- Quarterly sales effect

The insertion process is a commercial deliberation. In the regular process a first promised delivery date is given, based on the first manufacturing promise. When the customer is not satisfied with this first promised delivery date, he can request for earlier delivery. It is up to GEP to fulfill this request, based on commercial deliberations. It happens that other PO's are late released due to the insertion process. Therefore it is important that there is sufficient understanding of the impact on other PO's.

The quarterly sales effect is caused by sales targets. All orders that can be shipped within the current quarter get priority over orders that must be shipped outside the current quarter.
It is not expected that the quarter sales effect will be brought to an end, because it is a result of company targets. Changing this quarter sales effect is a complete separate project, so from now, the quarter sales effect will be considered as given.

[L-3] System bug confirmation around weekend

During the analysis, a system bug was discovered in the logic for calculating the first promised delivery date (1^{st} PDD). Sometimes the 1^{st} PDD is based on the first manufacturing promise. The distribution lead time is equal to the transportation time plus one day warehouse handling. The day warehouse handling is used to make an appointment for transportation. Manufacturing is working seven days a week, Distribution only during weekdays.

Now when the order is planned to finish during the weekend, the system calculated that day as the warehouse handling day. However, appointments can only be made during the weekdays. Result is that the 1^{st} PDD, and therefore also the first manufacturing promise, is one day too early. This problem is addressed to the supply chain department. They implemented a new logic in week 15 of 2007 to solve this bug.

[L-4] Time difference 1^{st} promise

A first manufacturing promise is generated when an order is scheduled. In general the complete scheduling cycle is finished before first promise is determined. However, sometimes the scheduler makes a second import of new PO's before the first promise is determined. These PO's are then automatically scheduled within the current schedule. Then the first promise is based on that position on the schedule.

The next day, the new PO will be rescheduled in the next scheduling cycle. A possible reason is that the PO is scheduled on another line. However, at that moment the first promise was already generated. So rescheduling such a PO to a later start will cause a late release. This is called a time difference first promise.

A second import of new PO's is not usual. However, when it is done the scheduler should reschedules all new PO's immediately, to avoid the time difference. Root cause for this driver is;

- First promise based on unadjusted detailed schedule

This issue is solved when the scheduler immediately reschedules all new PO's after a second import. However, this is not a very robust solution.

[L-5] Execution Line Delay

When actual production is slower than planned, this is called execution line delay. Because of round the clock production, it is not possible to catch up with plan. Result is that free time between orders is consumed. However, often there is no free time available between orders, and the orders are all rescheduled to a later planned start. This symptom is called bumping in GEP terminology.

Execution line delay itself can have several causes, for instance line break down, remake and extra cleaning. The causes for execution line delay are already known, because the plant is measured on execution. Besides the execution line delay itself, the main causes for this driver for late release are;

- Lack of scheduling margin (target earliness).
- Inaccurate throughput time estimation.

The smaller the scheduling margin, the higher the chance that bumping causes a late release.

Analysis shows that the current prediction model of the throughput time is not in line with reality. Therefore the capacity loading of the line is not accurate. The first promise is determined based on this detailed capacity loading schedule. Hence, a more accurate prediction model is necessary.

[L-6] Reallocation from other plant

Sometimes a plant has troubles producing an order. Then the order must be produced on another plant. However, the first promise was generated based on the schedule and the distribution lead time of the first plant. It is assumed that reallocation from plant is unavoidable. So even though the impact of this driver is high, no attempt will be made to solve this issue.

[L-7] Time difference RDD change

When the customer changes the Requested Delivery Date (RDD), the order is considered as a new order for the scheduling system. Result is that a new first promise is generated as well.

Now suppose that the PO was originally scheduled on target earliness and the line is completely loaded. When the customer adjusts its requested delivery date four days later, the PO cannot be rescheduled anymore because the line is completely loaded. This results in lack of scheduling margin.

The RDD change can never be the only reason for late release. However, the resulting lack of scheduling margin creates an opportunity for the other drivers. Because the customer is responsible for giving a correct RDD, no attempt will be made to solve this issue.

Summary root causes late release

Analysis of late releases resulted in a top seven of most common drivers, which are responsible for 88% of all the manufacturing late PO’s on Δ2 production alignment. Of the seven listed drivers the *system bug around the weekend* is already solved. *Reallocation from other plant* and *time difference RDD change* will not be solved. For the remaining four listed drivers, the root causes are determined. This root cause analysis can be found in a fishbone diagram in appendix O.

The most important driver is the *sequence optimization*. The first promise is decided based on a detailed schedule. However, the future state of the schedule is not known. Therefore sequencing is done just before releasing the orders for production. The most important root cause late release is the lack of scheduling margin.

The *FCFS overruling* caused by the quarterly sales effect will be considered as assumed. However, another cause is the insertion process. This cause is a commercial deliberation and will therefore not explicitly be addressed in this report. On the other hand, this report can help with gaining insight in the impact of the insertion process on other PO's.

The root cause for the driver *time difference 1st promise* is that manual intervention is needed to get a correct first manufacturing promise. Without this human intervention, the first promise is generated from an incorrect detailed schedule.

The most important root cause for *execution line delay* is the incorrect throughput time prediction. This causes an inaccurate capacity loading. The first promise is based on this incorrect loading profile.

Results early release

In this section, a pareto analysis of early release will be presented and explained. 493 of in total 1130 PO's are early released. One of the reasons for this high number is that during the data collection phase, demand was very low, causing orders to be pulled in into production.

The complete representation of the pareto analysis of drivers for early release is presented in appendix P. The top two drivers are responsible for 69% of all early releases. However these drivers are not influenced by the first manufacturing promise, but by other processes. Therefore figure I-2 shows only driver three to seven. The complete top seven drivers are responsible for 96% of all early releases.

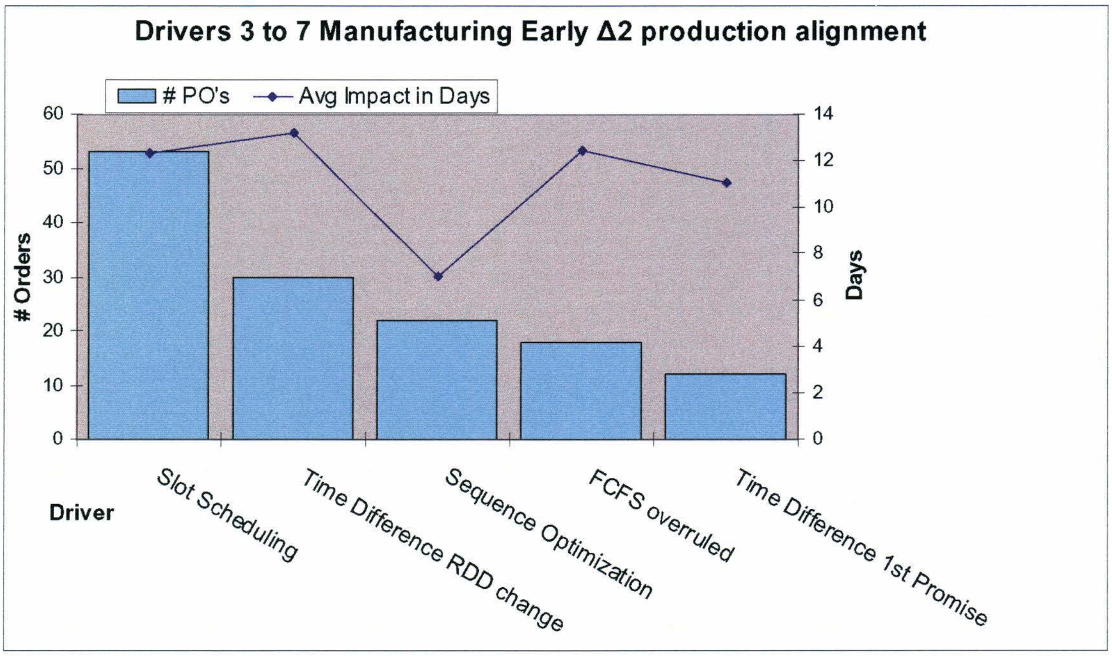


Figure I-2: Pareto drivers 3 to 7 Manufacturing Early Δ2 production alignment

The first two drivers, which are not shown in figure I-2, are *low order load* and *target earliness*. The root cause of both drivers is the low demand. To keep extruders running, orders are pulled in earlier. To automatically plan the start time of orders earlier, the target earliness is set to a higher number.

The main reason why the lines are not stopped is because the plant has quarterly production targets. Keeping the lines running is considered more important then low inventories. It might be wise to conduct research to the trade off in costs and benefits of this policy. However, because it is not related to delivery to first promise, it is not included in this thesis.

The remaining five drivers are responsible for 89% of the remaining early releases.

[E-3] Slot scheduling

PSP schedules PO's in timeslots. This slot scheduling is not flexible. When a PO is scheduled in a slot it will not be rescheduled without human intervention. Therefore, a new order must find a time slot that is large enough. Result is that small orders get higher priority than large orders, as illustrated in Figure I-3.

This illustration shows that the first come first schedule rule does not work correctly in PSP, because empty timeslots are distributed between the different scheduled PO's. For example for PO 1 there is enough capacity free to produce as requested, but because the capacity is scattered, it will be scheduled later then requested. Then PO 2 will be scheduled in front of PO 1, because it is scheduled in the least early slot. Finally PO 3 will be scheduled even earlier then PO 2, because that is the least early available slot left. So the PSP first come first scheduled priority rule schedules the PO's in sequence 3-2-1. When considering the total available capacity, PO 1 would be scheduled on time and the PO's would actually be scheduled in sequence of arrival 1-2-3.

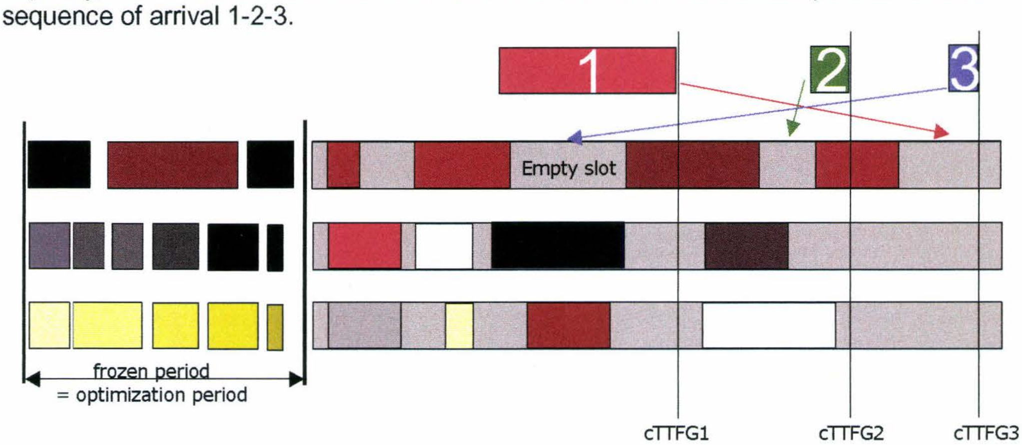


Figure I-3: PSP detailed scheduling method

This effect is strengthened when the throughput estimate of a large order is more than 24 hours. It is possible that on every day a timeslot is occupied with a small order. This causes an insufficient size time slot for the large order. In reality it happens that this will cause the large PO to be scheduled more than 30 days later than requested, even though there is enough total free capacity. When the human intervention is omitted before the first promise generation, this will cause an unsatisfied customer and a possible early release.

During the data collection, the focus was still on delivery to request. So once the scheduler notices that there is enough free capacity for the order, it is rescheduled to an earlier start. However, when changing to delivery to first promise, it is important to proactively reschedule these new orders before the first promise is generated.

Another downside is that the new PO's are assigned to a production line only the first time. From then the only possibility for a change between production lines is by human intervention. This means that product A that not necessary needs to be produced on line X, blocks capacity for product B that can only be produced on line X. It is also possible that the capacity was blocked for no reason, because finally the manufacturing scheduler decides to schedule product A on line Y.

As mentioned before in the drivers for late release, the throughput estimation for a PO is not modeled correctly by PSP. For now it is enough to explain that the planned throughput time for large orders can be 75% larger then the actual extrusion time. Result is that the occupied time slots are larger than needed and therefore the free time slots are smaller.

The root causes for slot scheduling are;

- Human intervention needed due to inflexibility (Fixed / Scattered free timeslots)
- Incorrect throughput time prediction

[E-4] Time difference RDD change

Time difference RDD change was also a driver for late release. However, the impact on early release is larger. After a RDD change, the order is considered as a new order, including a new first promise.

The schedule is updated about the RDD change on the moment of importing new PO's. Most of the time the RDD change is done after this import of new PO's, but before first promise generation. Because the schedule is not informed yet about this RDD change, the first promise will be based on the old schedule. The next day the order will be rescheduled based on the changed RDD, causing a manufacturing early.

Just to make this issue clear by an example from reality. On day 1 a PO has a cTTFG of day 50 with a pTTFG of day 46. The first promise is therefore day 50. Now on day 2 around 1200 hours, the customer changes the cTTFG to day 16. Because the 'new PO' import is already done, this change is not captured by the schedule. The first promise procedure now gives a new first manufacturing promise, based on the maximum of pTTFG and cTTFG. In this case the pTTFG is still day 46, so the first manufacturing promise will become day 46. On day 3, the new cTTFG is available on the schedule. There is enough capacity available, so the PO is rescheduled to target earliness on day 12. So the second promise will become day 16, which is equal to the new cTTFG. This second promise is exactly 30 days earlier then the first promise.

To give a little insight in the dataset, the average number of days early due to this driver is approximately 13 days. The smallest manufacturing early was 4 and the largest 29 days.

The new philosophy is to stick to first promise, even when it is possible to deliver earlier. But when the first promise is incorrect because of this rigid promise determination process, it might be wise to adjust the first promise.

[E-5] Sequence optimization

Sequence optimization is already explained as late released. Therefore the root cause is only shortly summarized. Sequencing is currently done to minimize cleaning time. When the order was already scheduled on target earliness, rescheduling the order to an earlier start will cause an early release.

[E-6] FCFS overruled

Overruling of the FCFS policy was also a driver for late release. For early release, it involves the PO that is scheduled earlier due to the two given causes. The first cause was quarterly sales effect and the second was insertion PO.

[E-7] Time difference first promise

Time difference first promise was also a driver for late release. Sometimes an additional import of new PO's is performed without rescheduling the new orders. The impact on early release is similar to the impact on time difference due to RDD change. However, the main difference is that the time difference is easily avoidable.

Because the first promise is generated when the order is scheduled, sometimes the additional import is performed. The additional import is often related to the quarterly seasonal effect. Then speed of first promise determination is considered to be important, because it can generate more sales for that quarter. This indicates that usually the speed of first promise determination slower.

In example, an order entered around 10 o'clock is not imported to the schedule the same day, because the import is done around 9 o'clock. Then the order will be scheduled the next day. The first promise determination is around 16 o'clock the second day. So the difference between order entry and first promise determination is then around 2 days. This is another downside of generating the first promise based on a detailed schedule.

A second import of new PO's is not usual. However, when it is done the scheduler should reschedules all new PO's immediately, to avoid the time difference. Root cause for this driver is;

- First promise based on unadjusted detailed schedule

This issue is solved when the scheduler immediately reschedules all new PO's after a second import. However, this is not a very robust solution.

Summary root causes early release

Analysis of early releases resulted in a top seven of most common drivers, responsible for 96% of all the early releases. The top two, being *low order load* and *target earliness*, are not caused by the first promise procedure. These drivers are caused by the low demand during the period of data collection. The orders are pulled in to keep the extrusion lines running. A suggestion is made to conduct research to the trade off in costs and benefits of stock building versus low inventories.

The top two drivers are responsible for 69% of all the early releases. For the remaining five listed drivers, the root causes are determined. This root cause analysis can be found in a fishbone diagram in appendix Q. The remaining five drivers are responsible for 89% off the remaining early releases.

Slot scheduling is considered as the generic term for the incapability of PSP. The PSP slot scheduling causes several sub problems;

- Small orders get higher priority over large orders
- Incapable of optimization between lines
- Incorrect capacity loading profile

Time difference RDD change, *sequence optimization* and *time difference first promise,* are also caused by the incapability of PSP.

FCFS overruled is considered to be a commercial deliberation and therefore not explicitly addressed in this report. However, this report can help to get insight in the impact of overruling the FCFS rule.

J. First manufacturing promise logic

The **first manufacturing promise** is defined as the latest day that manufacturing can transfer the PO to finished goods, so that the corresponding SO can be delivered on time according to the distribution lead time.

For MTI products there is no direct SO involved, and the customer is the GEP warehouse, after all, the products are produced on stock. Hence, again the main focus will be on MTO products. In this section, the logic will be presented on how the first manufacturing promise is determined.

Basically the first manufacturing promise is linked to the first customer promise. In some cases the first customer promise is derived from the first manufacturing promise and in the other cases it is done vise versa. There are three different possible scenarios, all shown in figure J-9. Scenario 1 represents the case where the first promise delivery date is determined based on the first manufacturing promise. Scenario 2 represents the case where it is the other way around and scenario 3 represents the case where a first manufacturing promise is create even though the product is not on the schedule yet. This is only possible when an order is outside the current scheduling window, due to early order entry. In the example below this scheduling window is set to 8 weeks.

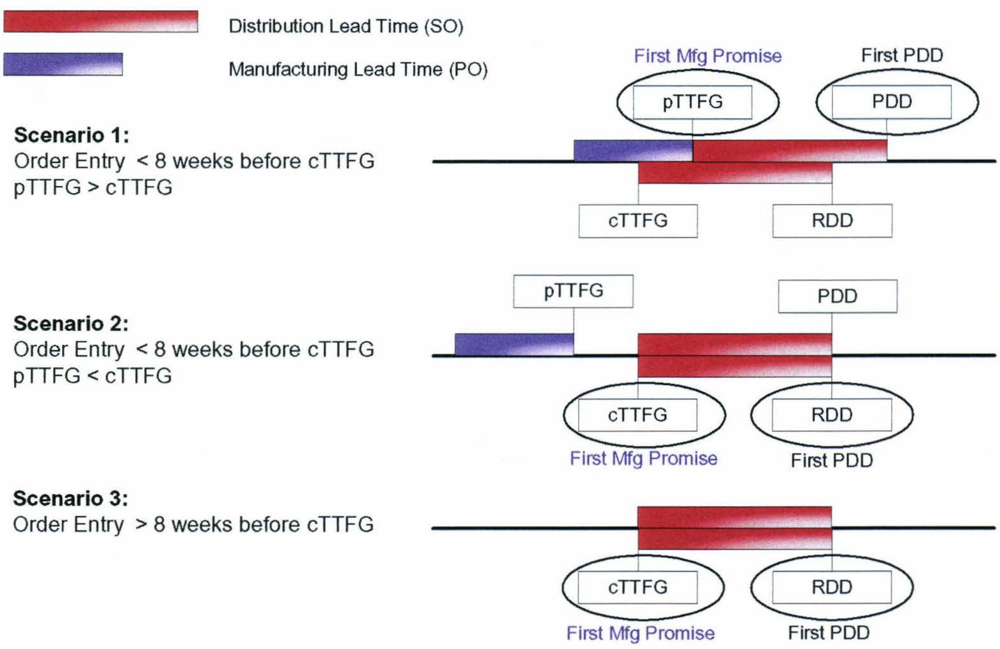


Figure J-9: Logic for first manufacturing promise and first promise delivery date[5]

The timestamp pTTFG is a rolling date, so it can change day by day. Timestamps like first manufacturing promise, cTTFG and aTTFG are generally not changed, apart from exceptions. The first time that an order is scheduled, it is attempted to schedule the order on a given target earliness. How PSP works in more detail is explained in appendix K. The target earliness can be set per plant and for the Lexan plant it is currently set to four days. This means that first it is tried to schedule every order for pTTFG, four days before the cTTFG. This immediately explains the difference between first manufacturing promise and the first pTTFG. The first manufacturing promise is the latest date that manufacturing should deliver the goods and the first pTTFG is the first planned TTFG date on the schedule.

[5] Since the start of this project, some changes in this logic are made. These changes will be reflected later on.

K. PSP

Introduction

In 2001, Production Scheduling Process (PSP) was implemented in the central planning department of GE Plastics and rolled-out for all the different plants.
PSP relies on static data (e.g. effectivities, line rates, etc) as well as dynamic data (orders, outstanding production) in order to get an updated picture of production scheduling.

Initial Scheduling System Solution

The scope of the system at the time of creation was defined as: [PSP Design documentation]. The system should schedule the extrusion process only, although packing and QA leadtimes should be taken into account. The system should take account of plant constraints and business objectives to create feasible schedules.

The system will process short-term schedules based on the business rules. These rules will be interpreted in the system via a number of parameters and penalty values.

The number of days to be scheduled will also be a parameter within the system. This parameter should be set such that all the orders in the system can be scheduled. The orders in the system will be controlled by a parameter, which tells APAg which orders to load based on the cTTFG. There will be no capacity planning, long- or medium-term scheduling, and no planning of ideal inventory or distribution. It is assumed that these processes are handled by other systems. The system will not include any modeling of raw materials.

The objective of the implementation was
Minimize the number of human actions required in scheduling
Optimize the quality of the schedules

Formulation of the model in PSP
The total scheduling horizon will include a "backorder horizon" some time in the past, and an "optimization horizon" of a number of days into the future. Setting the start date in the past will ensure that the system will see orders with due dates before the current date as more urgent than orders due on the current date. This thus means that if a client gives an order with a very short requested due date this will trigger the system to give it extra priority. This is known in GEP as the "bumping" effect, as late orders bump the already planned orders. Since 2005 the rule has changed, and the incoming date defines the priority of the order, the priority rule is thus First In First Out (FIFO).

The first x hours of the schedule will be frozen. This will be set in a parameter.
The modeling in PSP is based on the extrusion lines in the plant. Every line is defined by a code.
The products are modeled as inventories, to ensure that there is only one production activity for each order. This rule also allows aggregation to be a post-scheduling optimization rather than a pre-scheduling decision.

A product is defined by a code consisting of four codes: grade-colour-specification-packaging.
Down time is scheduled by a special inventory, which will be used to ensure that no production activities are scheduled over planned down time when creating the initial schedule.

Objectives, constraints & penalties of the model
During creation of the schedule and subsequent optimization, the system can consider the following objectives. Parameters and penalties will determine which objectives are considered and their relative importance.
Minimize the difference between the pTTFG and cTTFG for each order. This value for Priority orders will be considered more important than for standard orders. This will be modeled by penalizing late orders and early orders. This will be regarded as the measure of whether one

schedule is better than another. The penalties for Priority orders will be higher than for standard orders.

- Aggregate orders for the same product
- Minimize change-overs
- Use preferred resource
- Respect Due dates. Where possible the system will try to ensure that orders are scheduled before their Due dates.
- Respect Earliest Dates. Where possible the system should try to ensure that no orders are scheduled before the Earliest Start Date.
- No late orders scheduled after early orders

The system will attempt to ensure that there are no late orders scheduled after an early order on the same Resource. An order is early if the pTTFG day is before the cTTFG day. An order is late if the pTTFG day is after the cTTFG day.

The following constraints are modeled (bold text indicates hard constraints which will not be broken by the automatic scheduling). Note: if the system is over-constrained it may be necessary to change some of the hard constraints to soft constraints in order to process a workable schedule.

- Maximum Available Time per Resource
- Production Rates: A single rate for each Order/Resource option.
- Valid Resources: Orders will only be scheduled on valid resources as defined by the effectivities.
- Change-over Times: Correct change-over times will be applied between activities.

The objectives mentioned above are modeled by setting the penalty costs in the system.

The pTTFG, thus the planned time for transfer to finished goods is calculated in PSP by:
pTTFG = Scheduled End + QA/Pack time
The QA pack time is defined as a lead time to cover the time between the end of extrusion and the time when the order is received in Finished Goods. This time is imported for each order activity.

New scheduling approach

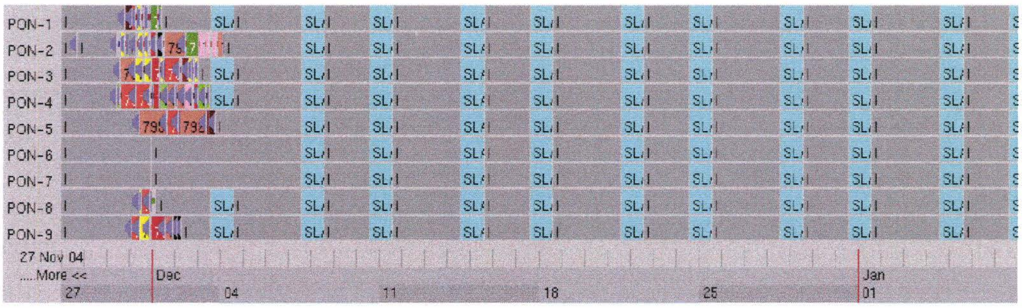
In 2003 the requirements of the system changed to increase focus on On-Time-Delivery. The benefits of the change were formulated as:

- Reduction of the number of re-confirmations per customer Rewarding customers who order in time with reliable on time delivery
- Increasing the reliability of the delivery confirmation to customers

In order to meet these requirements, a new approach to scheduling in PSP has been created. Instead of relying on PSP standard construction algorithms guided by penalty costs, the core of the new scheduling approach is a bespoke scheduling algorithm (schedorder) that includes GE business rules.

The schedule is composed of frozen order activities (corresponding to batches that have been launched in production).

We add SLACK activities in the horizon to reserve capacity in order to be able to catch up during execution and therefore ensure that problems on the line are not bumping (i.e. delaying) orders later on, resulting in re-confirmation and an unstable schedule. Orders are inserted into available slots (i.e. idle activities) following the scheduling logic embedded in the schedorder procedure:



Change-over matrix (SWAC table).

For the sequencing of the products the change-over time must be defined between the products in the frozen schedule. The procedure for this in PSP relies on groups. Each color code and grade code are assigned to a color group and grade group respectively. In the tables GRADE_TRANS and COLOR_TRANS transition letter between grade groups and color groups are defined. The algorithm in PSP that looks up the necessary codes as follows:
Build a list of all activities and a list of new activities.
Loop through relevant SWAC values to update and calculate them

Logic for change-over code calculation

- Variables with suffix 1 correspond to the activity we change from and variables with suffix 2 to the activity we change to.
- All the possible change-over codes should already be defined in the ACT list, between A_CO and Z_CO and their duration defined in the ACTI table column TARA.
- The change-over code is blank (i.e. no change-over) is color_code1=color_code2 and grade_code1=grade_code2. Otherwise, we get the transition code corresponding to grade group change (from the GRADE_TRANS table) and likewise the transition code corresponding to the color group change from the COLOR_TRANS table. We also get the corresponding change-over duration from the ACTI table.
- Transition code (and therefore the change-over code) is chosen corresponding to the maximum change-over duration of the grade and color matrix.
- If one of the two transitions is not defined (because the group is DEFAULT or the transition hasn't been defined) then we only use the other defined transition.
- For a double exception (both transitions are not defined) then we choose the shortest change-over on the resource.

Order scheduling
The procedure schedorder is at the core of the new scheduling approach. Its purpose is to schedule an order in the plan in the best possible place without disturbing any other existing activities (in that sense it is intended to be used in an incremental scheduling approach.)
The algorithm steps are as follows:

1. Find all the resources where this order can be scheduled
2. Build a list of all possible solutions
3. Select best solution
4. Add the best solution into the schedule (if option execute = yes)

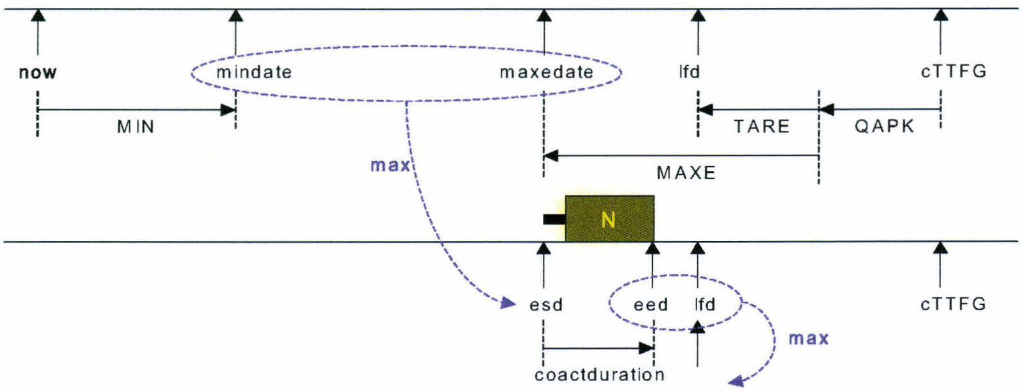
1) Find all the resources where this order can be schedule
All resources where the order can be scheduled and the preference of the effectivity are identified.
Target date and the earliest date for the activities are calculated.
lfd (latest finish date) = cTTFG – (QA Packing Time) – (Target Earliness)
maxedate (max early date)= cTTFG – (QA Packing Time) – MAXE
mindate = now (rounded to the hour) + MIN

Target Earliness is a given timeframe.
Mindate represents the earliest a batch can be started, given a constraint defined in the SLACK table for minimum separation from an earlier blending stage that is not represented in the PSP model.

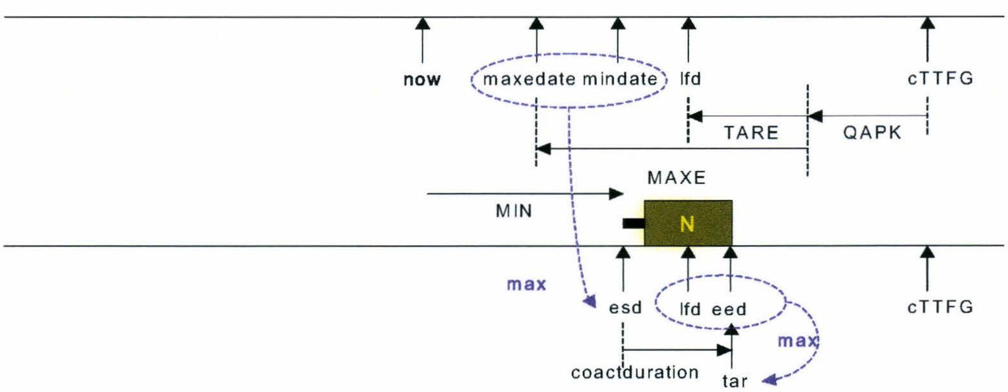
The max (or latest) of mindate and maxedate represents the earliest start date (esd) for the order. Adding the change-over and the activity duration (coactduration) to esd defines the earliest end (eed) date for the activity.

The target date for the activity (tar) is the max (or latest) of eed and lfd.
This procedure ensures that the target date and the earliest start date take all the constraints into account.

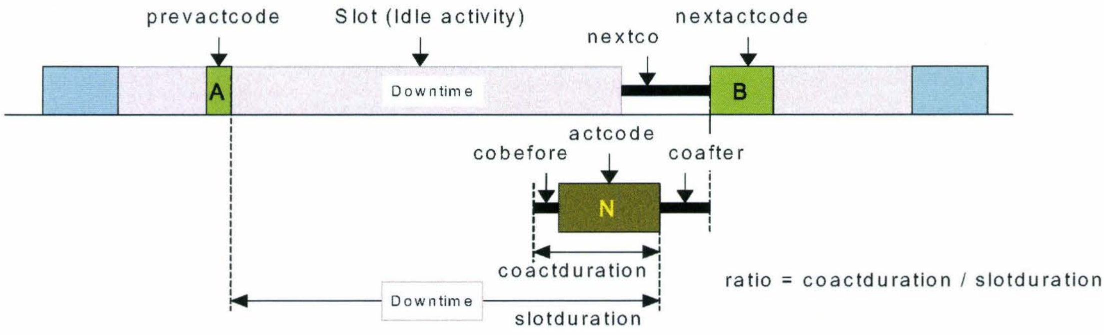
There are two main cases.
The MIN constraint is not affecting the target date:



The second case is where the MIN parameter, together with the current date (now) is pushing the earliest start date and possibly the target date too:



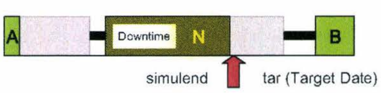
2) Build a list of all possible solutions
For each resource where the order can be schedule, all possible slots are defined. A possible slot is defined a an unfixed idle activity which end date is after earliest start date.
The procedure is visualized in the figure below.



The slotduration takes into account the change of change-over activity (fir this example: insertion of N between A and B will change "nextco" (A → B) into "coafter" (N → B), as well as the fact that planned downtime might exist that isn't available capacity or scheduling the order in the slot.
Coactduration is the sum of the duration of the order on that resource with the duration of the change-over from prevactcode to actcode (A → N).
Ratio is the ration of coactduration and slotduration.
A feasible solution exists only as ratio ≤ 1.
If this is the case, the positioning of the slot is simulated. There are 2 cases. depending on the position of the Target Date relative to the slot.

The activity should be at either end of the slot:

The activity should be in the middle of the slot:



For the second case a SLOT parameter controls the splitting up of the slot, if that if ratio ≥ SLOT the slot is not split. If this is the case, earliness is preferred to lateness and the order is placed at the beginning of the slot.

For the solution of scheduling the order in that slot the difference between the simulated end of the activity and the Target Date is calculated:

Difference = simulendsec – lfd

If the absolute value of diff is less than a so-called "FUZZ" parameter, difference is (this is used to get selection of the solution on the preferred resource later when the difference is quite negligible, otherwise an on-time solution on a non-preferred resource would be selected over a solution late by a few minutes on the preferred resource).
Note that difference and FUZZ are expressed in hours.

Finally, this solution is added to the solutions list as simulend is not earlier than Earliest Date (esd.)

For late solution (different > 0) further slots on the line are not checked, as this would generate only later solutions.
Based on difference, the solution is placed in either of the 3 following lists:

ontimesolutionlist (difference = 0)
earlysolutionlist (difference < 0)
latesolutionlist (difference > 0)

3) Select best solution

The selection process for the best solution is as follows:
Are there any on-time solutions? If yes, best solution is the one with lowest preference (from effectivities) followed by shortest duration (if same preference.)
Otherwise, are there any early solutions? If yes, the best solution is the least early one followed by shortest duration (if same earliness.)
Otherwise, are there any late solutions? If yes, the best solutions is the least late one followed by shortest duration (if same lateness.)

4) Add the best solution into the schedule

If option execute = "yes" then the best solution is added to the schedule. Otherwise only return the resource code and the P-C corresponding are returned to the best solution found (this is used to test possible improvements in the improvepmc procedure without doing any actual change to the schedule.)

Optimize sequence

The purpose of the optimbycapa procedure is to optimize orders that are going to be frozen for the next export. Idle time and slack are not taking into account anymore; the goal is to minimize the change-over.
There are two options:

- Sequence procedure: every order is kept on the line where it was originally scheduled.
- Full procedure: assigns orders to the best line, based on lowest preference and shortest production time and minimizes change-over times.

The first solution is always feasible; the logic to build the optimized sequence on a line is in figure K-1.

The full optimize option is much harder and can create optimal solutions. This sort of problem can only be resolved to optimality by enumerating all the solutions and identifying the best one. The number of solutions grows exponentially with the number of orders and lines and such an approach is not feasible. The heuristic used tries to do the order assignment and sequencing optimization in one pass. All the orders are put into a list that is sorted based on the number of effectivities (in order to assign orders with 1 effectivity before orders that have more flexibility).

When there is a choice of more than one resource where to assign the current order, it is decided using capacity and preference criteria. After every assignment to a line, the sequence algorithm detailed above is used to find the optimal sequence (and therefore change-over durations) so that remaining capacity on that line can be known. If at some point an order could not be assigned to any line (because of lack of capacity), then solution is infeasible. In the case of an infeasible solution, the process is restarted, this time starting with the orders that could not be added to the schedule the previous time (before the orders with 1 effectivity even), hoping that it will help to find a feasible solution, although it is really not sure that it will. The process continues until a feasible solution is found or the maximum number of iterations as set in the procedure parameters is reached.

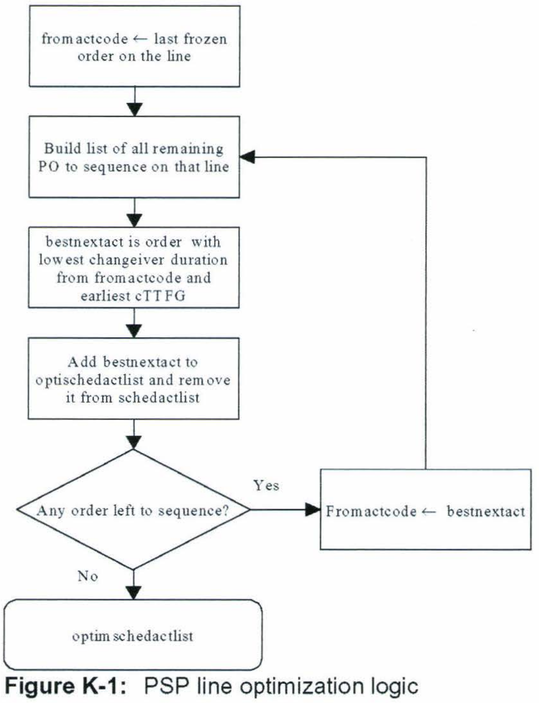


Figure K-1: PSP line optimization logic

L. Statistical Analysis main originators

Minitab Output

Correlations (Pearson)

	Production alignment	Production Execution
Production Execution	-0.028 0.435	
Delivery to 1st Mfg P	0.915 0.000	0.378 0.000

Cell Contents: Correlation
P-Value

Descriptive Statistics

Variable	N	Mean	Median	TrMean	StDev	SE Mean
Production Alignment	760	-3.767	-3.000	-3.430	5.061	0.184
Production Execution	760	-1.3789	-2.0000	-1.4064	2.2105	0.0802
Delivery to 1st Mfg P	760	-5.146	-5.000	-4.890	5.465	0.198

Variable	Minimum	Maximum	Q1	Q3
Production Alignment	-38.000	15.000	-6.000	0.000
Production Execution	-17.0000	13.0000	-2.0000	0.0000
Delivery to 1st Mfg P	-42.000	14.000	-8.000	-2.000

Regression Analysis (Production alignment)

The regression equation is
'Delivery to 1st Mfg P' = - 1.43 + 0.988 'Production alignment'

Predictor	Coef	StDev	T	P
Constant	-1.4256	0.1000	-14.25	0.000
Production alignment	0.98761	0.01586	62.27	0.000

S = 2.211   R-Sq = 83.6%   R-Sq(adj) = 83.6%

Analysis of Variance

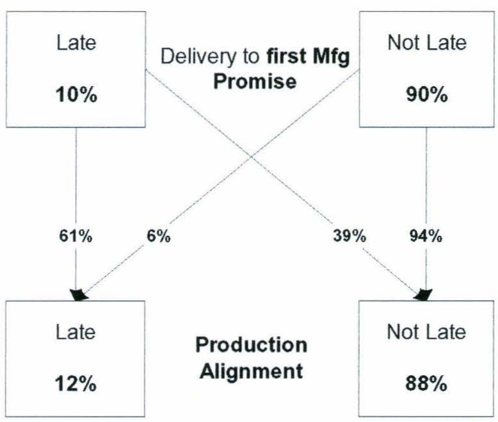
Source	DF	SS	MS	F	P
Regression	1	18959	18959	3877.86	0.000
Residual Error	758	3706	5		
Total	759	22665			

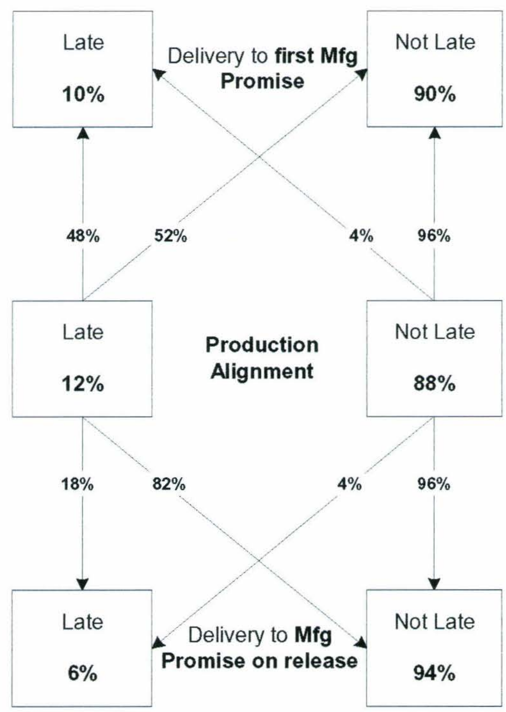
Regression Analysis (Production execution)

The regression equation is
'Delivery to 1st Mfg P' = - 3.86 + 0.935 'Production execution'

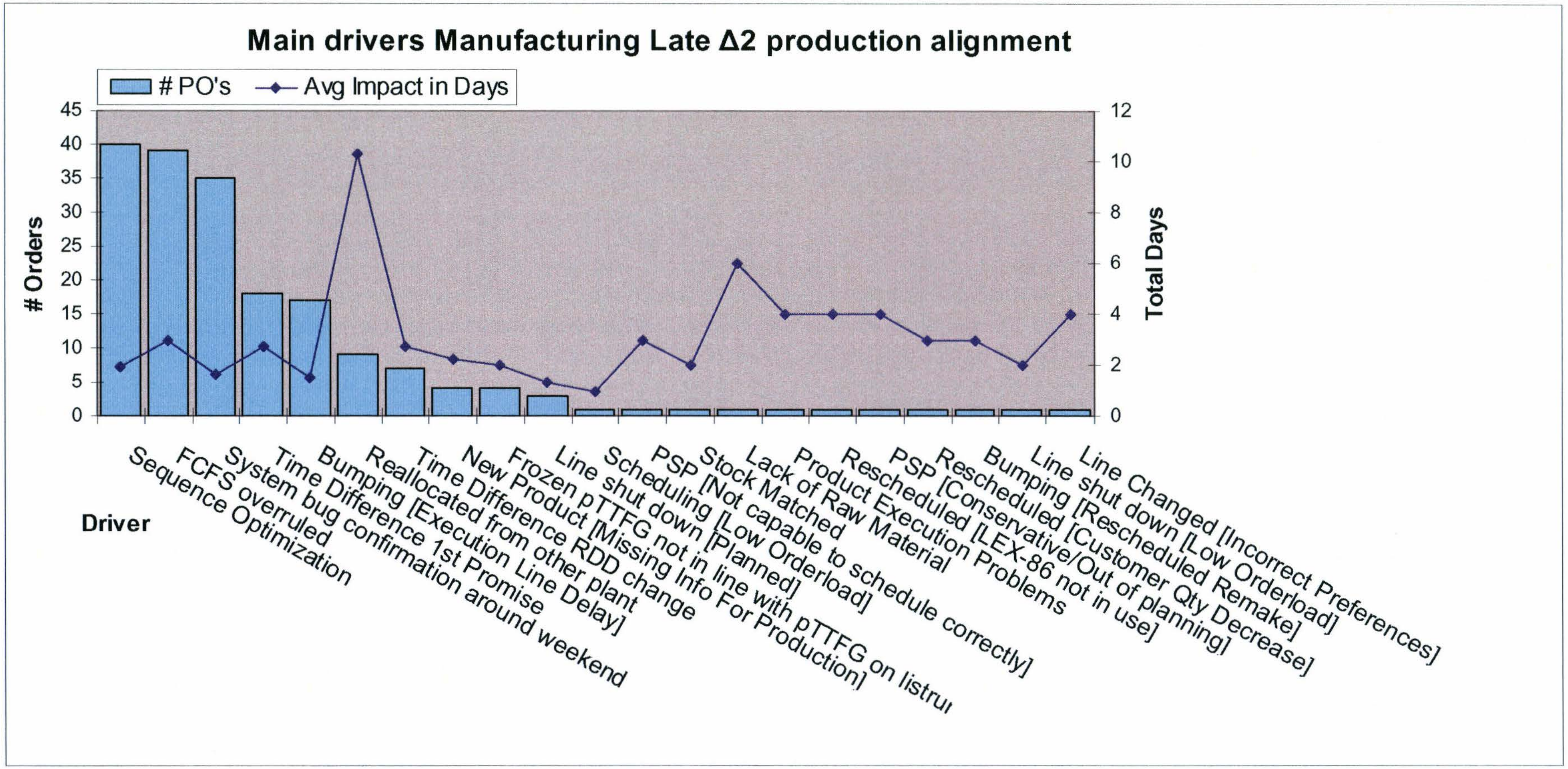
```
Predictor                Coef        StDev       T           P
Constant                 -3.8567     0.2165      -17.82      0.000
Production execution     0.93504     0.08312     11.25       0.000

S = 5.062        R-Sq = 14.3%     R-Sq(adj) = 14.2%

Analysis of Variance

Source             DF          SS          MS          F          P
Regression          1      3242.7      3242.7     126.55      0.000
Residual Error    758     19422.1        25.6
Total             759     22664.8
```

M. Split of PO's in late and not late

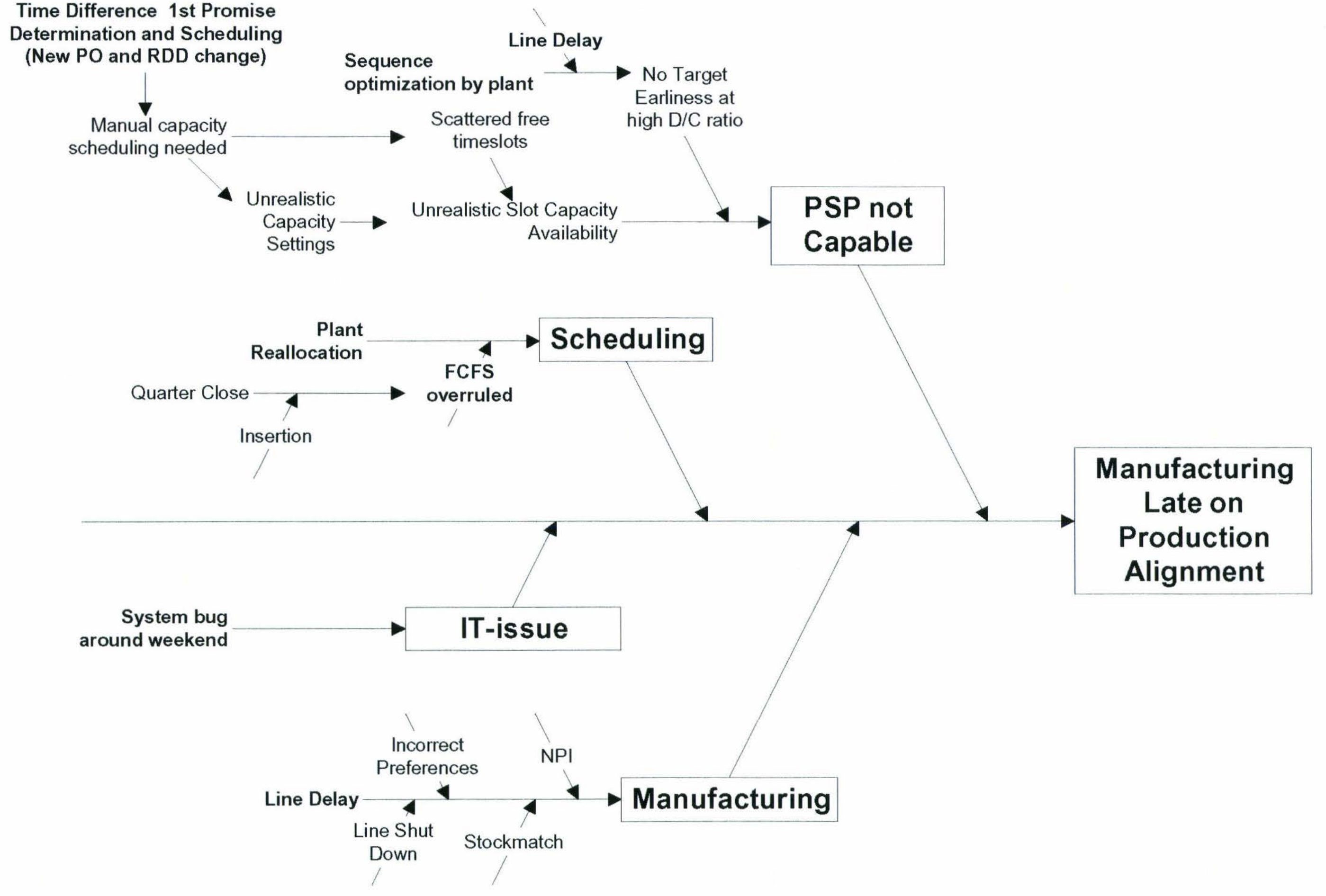




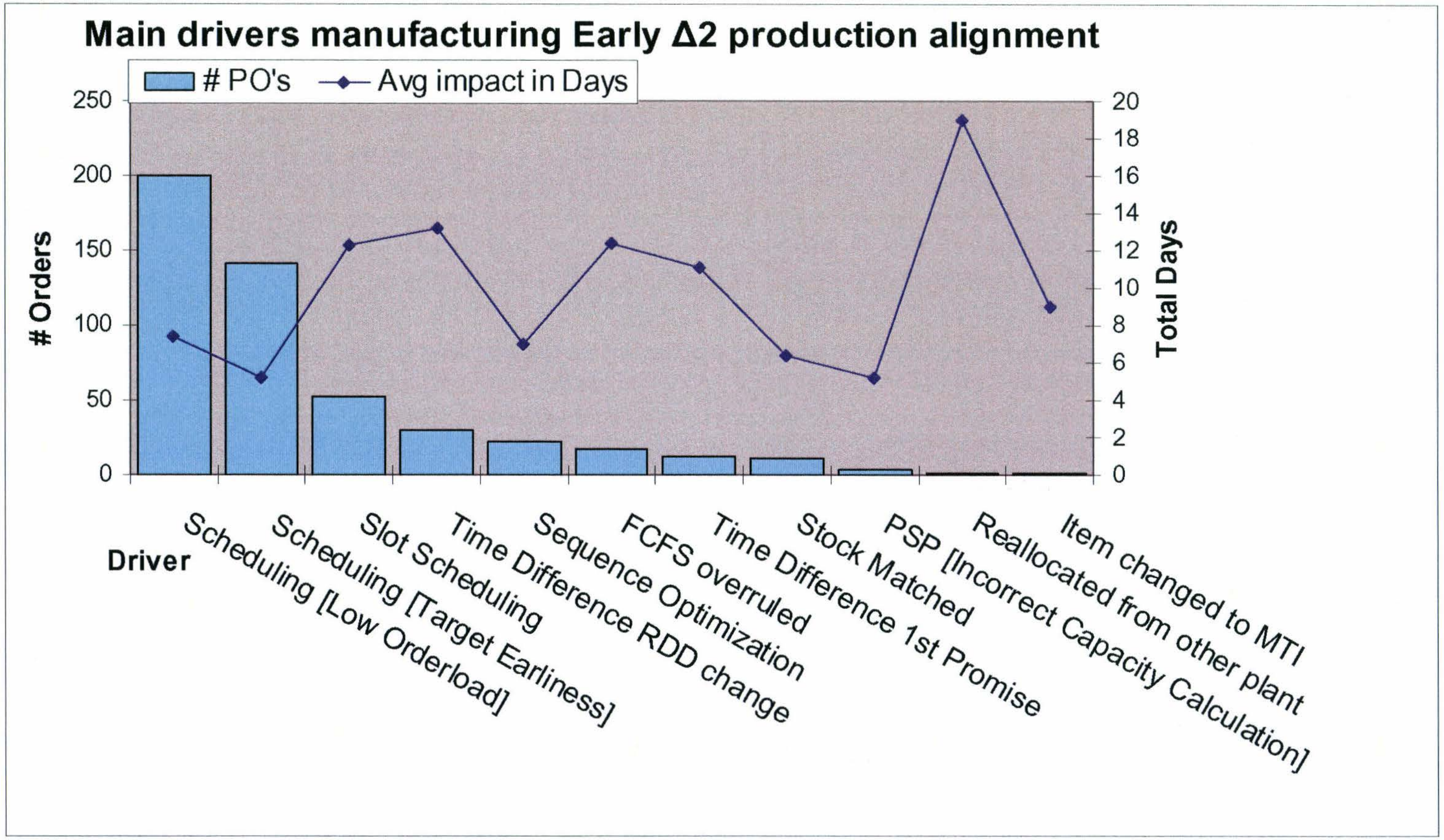
N. Pareto Manufacturing Late



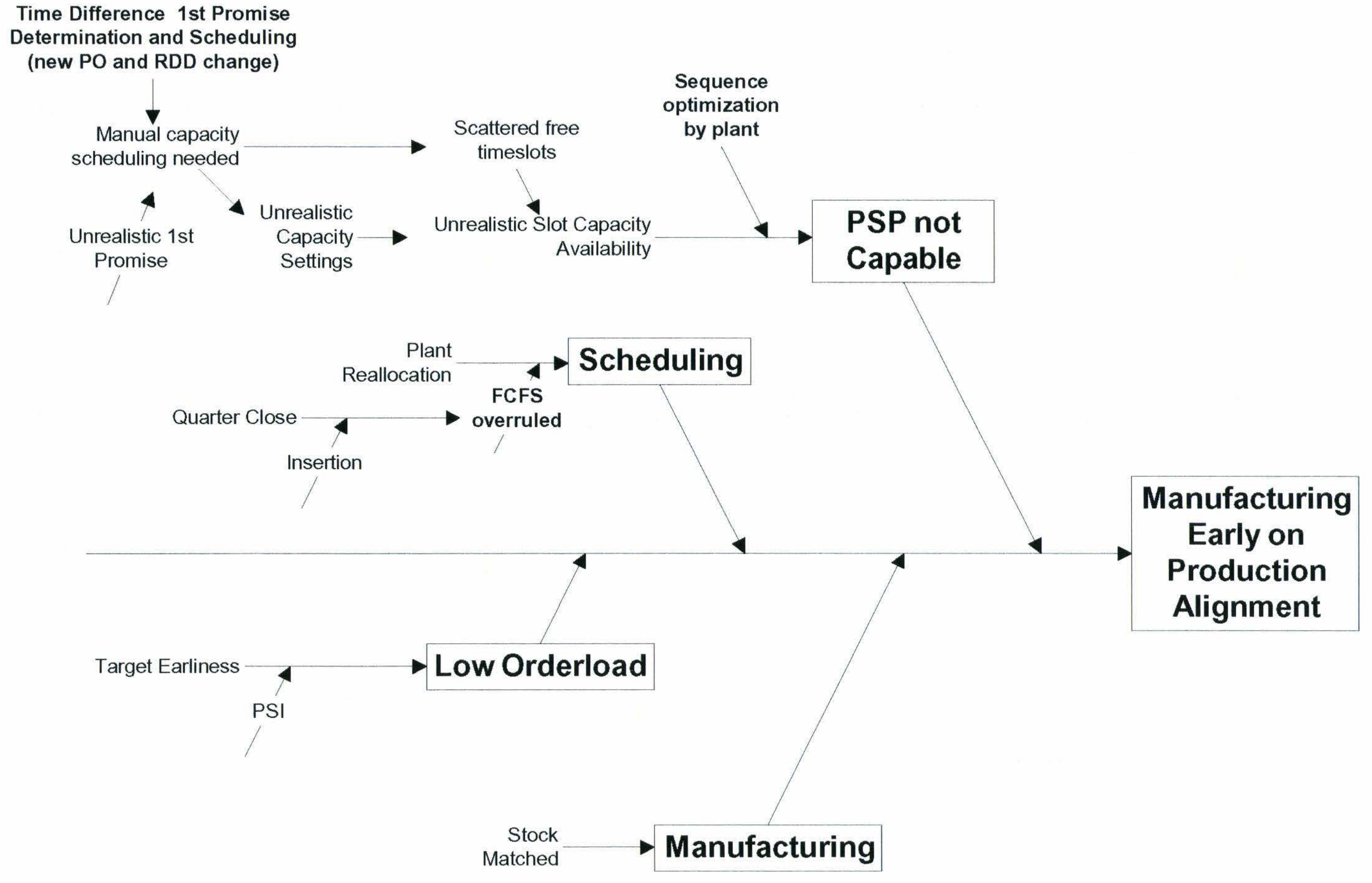
O. Fishbone Diagram Manufacturing Late



P. Pareto Manufacturing Early



Q. Fishbone Diagram Manufacturing Early



R. Chi square test on assumed normal distribution RR

Group	From RR	To RR	O(RR)	E(RR)	Chi^2
1	0	714.6461	32	23.9375	2.715568
2	714.6461	777.9939	23	23.9375	0.036717
3	777.9939	819.655	15	23.9375	3.336978
4	819.655	851.9767	19	23.9375	1.01844
5	851.9767	879.035	19	23.9375	1.01844
6	879.035	902.7165	16	23.9375	2.632017
7	902.7165	924.0617	19	23.9375	1.01844
8	924.0617	943.7118	20	23.9375	0.647683
9	943.7118	962.0948	26	23.9375	0.177709
10	962.0948	979.5134	17	23.9375	2.010607
11	979.5134	996.1937	27	23.9375	0.391808
12	996.1937	1012.312	23	23.9375	0.036717
13	1012.312	1028.011	30	23.9375	1.535411
14	1028.011	1043.413	16	23.9375	2.632017
15	1043.413	1058.623	27	23.9375	0.391808
16	1058.623	1073.739	29	23.9375	1.070659
17	1073.739	1088.855	31	23.9375	2.083714
18	1088.855	1104.065	33	23.9375	3.430973
19	1104.065	1119.466	31	23.9375	2.083714
20	1119.466	1135.165	27	23.9375	0.391808
21	1135.165	1151.284	29	23.9375	1.070659
22	1151.284	1167.964	24	23.9375	0.000163
23	1167.964	1185.382	20	23.9375	0.647683
24	1185.382	1203.765	25	23.9375	0.047161
25	1203.765	1223.416	28	23.9375	0.689458
26	1223.416	1244.761	29	23.9375	1.070659
27	1244.761	1268.442	19	23.9375	1.01844
28	1268.442	1295.501	19	23.9375	1.01844
29	1295.501	1327.822	16	23.9375	2.632017
30	1327.822	1369.483	16	23.9375	2.632017
31	1369.483	1432.831	19	23.9375	1.01844
32	1432.831	9999	25	23.9375	0.047161
				Total	40.55352

H0: The form of the distribution of RR is Normal(1074, 173)
H1: The form of the distribution of RR is not Normal(1074, 173)

$\chi_0^2 = 40.6 < \chi_{0.05,30}^2 = 43.8$

There is no reason to assume that the Run Rate is not normally distributed with μ = 1074 σ = 173

S. Analysis of behavior PDF changeover and run time

This appendix discusses the behavior of the probability density functions used for changeover and run time. Based on this behavior, it can be analyzed what will happen with the predictability of the changeover or run time, when GEP is able to change the mean or variance of both processes.

Changeover time

Now to get insight into the behavior of this function, the probability density function of a lognormal distribution is plotted in figure S-1. In this figure, four lines are drawn, each simulating an imaginary changeover time distribution. Based on these distributions it is analyzed what the effect of the variance is on the average changeover time. Therefore, variances are analyzed of 4 hours and 16 hours. It is assumed that after changing the variance, the changeover times are still lognormal distributed.

The red line in figure S-1 approximates the current actual changeover times; a mean of 4 hours, with a variance of 16 hours. The closer the peak is on the mean, the better the predictability of the changeover duration. The red line shows a rather unpredictable changeover time at a variance of 16 hours, because many changeovers take less time then the average of 4 hours.

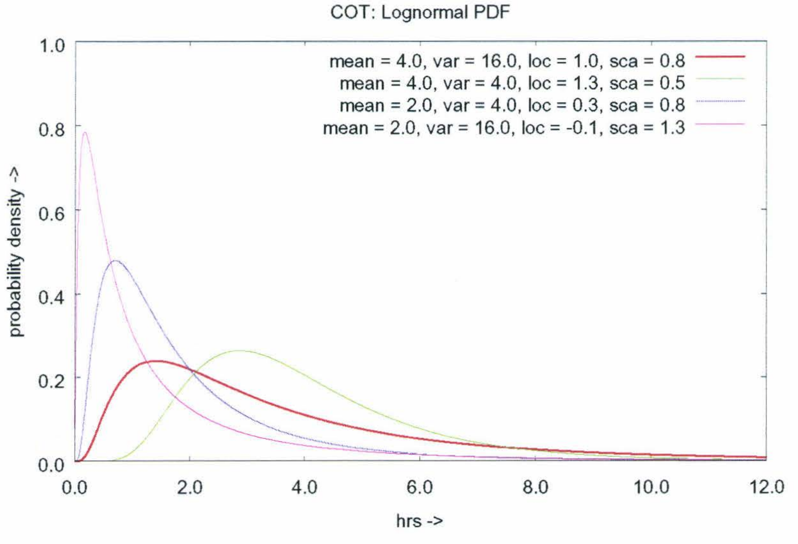


Figure S-1: Lognormal PDF corresponding to changeover times in Lexan

Now it is investigated what happens when GEP is able to reduce the variance to 4 hours, while the average remains the same. The green line shows that fewer changeovers are finished in a shorter time than the mean and fewer have extreme high values. In other words, the changeover times will be more predictable, what can also be measured by the scale.

The blue line shows what happens when GEP is able to reduce the variance to 4 hours and the mean to 2 hours. In hours, the changeover times become much more predictable, compared to the current situation. Relatively, the changeover times are still unpredictable, since the scale is equal to the scale of the red line. However, the total occupation of a line consists of changeover time and run time, so the predictability of total occupation will increase, even though the run time predictability remains stable.

The pink line shows the situation when the mean can be reduced to 2 hours, but the variance remains 16 hours. The scale parameter shows that the predictability is worse then the red line. Basically many changeovers take a very short amount of time, and few take a very large amount of time.

Run Time

To get insight into the behavior of this function, the probability density function of the run time distribution is plotted in figure S-2. The derivation of the probability density function can be found in appendix T. In the figure, four lines are drawn, each simulating an imaginary run time distribution. Based on these distributions it is analyzed what the effect of the parameters is on the variance of the run time.

The red line in figure S-2 approximates the current run time distribution of a 2500 kg PO. This also shows that the run time is indeed not normal distributed. This distribution has a heavy right tail, indicating an off centered mean.

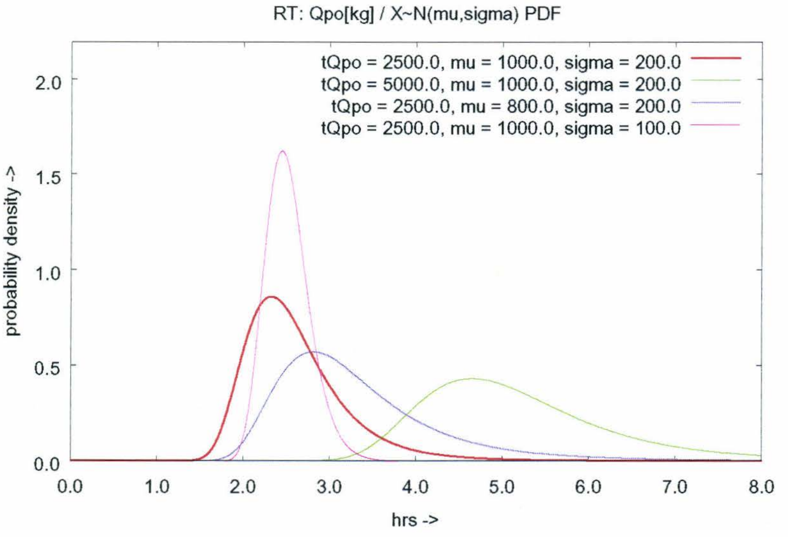


Figure S-1: Run time PDF with normal distributed run rate in Lexan

The green line approximates the current run time distribution of a 5000 kg PO. Compared with the 2500 kg PO, the variation is larger for the 5000 kg PO. This is logical, because the run time is related to the quantity and the run rate, and therefore also to the variation of the run rate.

The blue line simulates the case when the average run rate decreases while the standard deviation remains the same. This can happen for instance when the extruder is modified. Now the average run time increases and the variance in run time as well.

The pink line shows what happens when GEP is able to reduce the standard deviation of the run rate, without changing the average run rate. Now the predictability of the run time duration increases drastically. Measured in hours, this will have an extra effect on large PO's, as concluded with the green line.

Now the distributions for changeover and run times are known. The changeover time follows a lognormal distribution. The run time depends on the quantity of the PO and the run rate that is normal distributed. Due to these distributions, it is hard to investigate the average variance in total occupancy time of an extruder per PO. It is difficult to compare PO's of 2500 kg with PO's of 20 tons, because the balance between run and changeover time differs among the PO quantities.

T. Derivation Run Time CDF to PDF

$x = rt(tQ_{PO}) =$ run time [hrs] for a given quantity tQ_{PO} [kg]

$$F(x) = 1 - \Phi\left[\frac{\frac{tQ_{PO}}{x} - \mu}{\sigma}\right] = 1 - \left[\frac{1}{2} + \frac{1}{2} erf\left(\frac{\frac{tQ_{PO}}{x} - \mu}{\sigma\sqrt{2}}\right)\right] = \frac{1}{2} - \frac{1}{2} erf\left(\frac{\frac{tQ_{PO}}{x} - \mu}{\sigma\sqrt{2}}\right)$$

$$f(x) = \frac{d}{dx}F(x) = -\frac{1}{2}\frac{2}{\sqrt{\pi}} e^{-\frac{1}{2} * \left(\frac{\frac{tQ_{PO}}{x} - \mu}{\sigma}\right)^2} \frac{-tQ_{PO}}{x^2\sigma\sqrt{2}} = \frac{tQ_{PO}}{x^2\sigma\sqrt{\pi 2}} e^{-\frac{1}{2} * \left(\frac{\frac{tQ_{PO}}{x} - \mu}{\sigma}\right)^2}$$

U. Simulation summary throughput time

In chapter 4, the stochastic model is determined. It was also concluded that it is hard to determine the variance in total occupancy time of the extruder for a PO. Both the changeover and run time have their own variance. Besides, the variance of the run time is dependent on the quantity of the PO, so the variance of a single PO has a fixed part and a variable part. To get insight in the total variance, the stochastic model is simulated in Enterprise Dynamics[6].

The model consists of the two probability distributions for changeover and run time and a dataset of all PO's for LEX-17 from Q3 2006 to Q2 2007. To simulate an order set, PO's are randomly drawn from this dataset with replacement.

To validate the model, a check is done on average produced quantity per hour. Experts indicate that the average uptime of the extruder is approximately 50%, what results in a average produced quantity of 537 kg/hr, given a run rate of 1074 kg/hr. Every year approximately 800 PO's are produced. A simulation run of 10,000 PO's is done to compare the output of the model with the actual data. The simulation run results in an average produced quantity of 539 kg/hr, so it can be concluded that the model is valid.

The simulation run also shows that proportion changeover versus run time is equal to 40% versus 60%. So the simulation run indicates that approximately 40% of the extruder time is used by changeover time. Experts verify this. Bringing this in perspective with the 50% uptime of the extruder, this means that the largest amount of this 50% is caused by the changeover time. This indicates that reduction of changeover time is a large opportunity for increasing capacity.

To investigate the impact of the quantity of a PO on the variance, some simulation runs are designed, each with a different PO quantity. The result of this analysis is presented in figure U-1. It can be concluded that the variance of run time has a quadratic relation with the quantity of the PO. The variance of changeover time remains constant, because it is not related to the quantity of the PO. At a volume of 18,850 kg, the variance of the changeover and run time are equal to each other. Below that 18,850 kg, the variance in changeover time is the largest source of variance.

With 80% of the PO's smaller than 10.000 kg and an average production quantity of 5,600 kg, it is expected that most of the focus for LEX-17 should be on reducing the variance in changeover time. This remark was already made based on the fact that 40% of the total time was used for changeovers.

To investigate the actual contribution to the variance in total occupancy time of an extruder, a simulation run is created based on the dataset from Q3 2006 to Q2 2007. An order set of 60,000 PO's is created. The variance of changeover time is equal to 14.17 hours. The variance

[6] Enterprise Dynamics is a software program for object oriented simulation

in run time based on the quantity of the PO is equal to 2.49 hours. Hence, it can be concluded that the changeover time causes the most variance and therefore needs most of the focus for reducing variance.

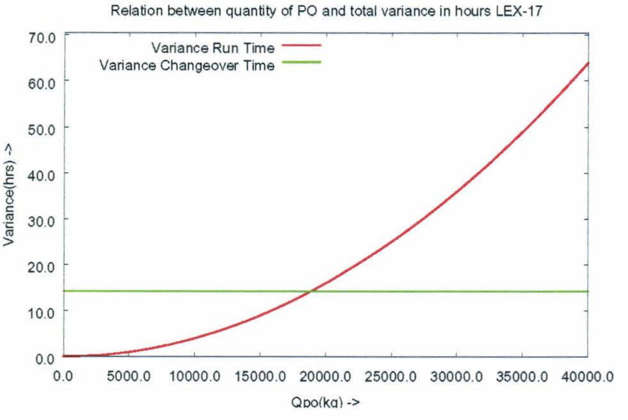


Figure U-1: Relation between quantity of PO and variance in hours LEX-17

V. Analysis improvements current lead time promise method

PSP schedules orders in timeslots. This causes scattered free time slots. PSP is not developed to be flexible in making timeslots larger by moving around orders. This is easily explained by an example. For instance, when an order arrives that is too large for an available timeslot, the order will be scheduled in another timeslot that is large enough. However, when the schedule is analyzed more closely, the scattered free timeslots together would provide enough time for the order. So that means that human intervention is needed to create a timeslot large enough to fit the order into the schedule. When this human intervention is omitted, the lead time promise is made based on the not optimized schedule.

Summarizing, the current GE Plastics lead time promise method shows the following shortcomings:

a. Lead time promise only given once a day
b. Not always the margin target earliness available
c. Human intervention needed due to timeslot scheduling

Many of the drivers for Δ2 production alignment, relate back to these shortcomings of the lead time promise method. Therefore, it is desirable that these shortcomings are solved in the current method. In this appendix is discussed in what extend the shortcomings can be solved in the current method. Also the impact on all drivers for late and early on Δ2 production alignment will be discussed. Some of these solutions are already implemented.

Shortcomings current lead time promise method

This section discusses some enhancements in lead time promise method, which will improve shortcomings. Furthermore, the impact on drivers for Δ2 production alignment performance will be analyzed. The top seven drivers for Δ2 production alignment late and early are given in table below. Drivers that are not affected by the three shortcomings will be discussed at the end of this section.

	Δ2 Late	Δ2 Early
1	•Sequence optimization	•Low order load
2	•FCFS overruled	•Target earliness
3	•System bug weekend	•Slot scheduling
4	•Time difference first promise	•Time difference RDD change
5	•Execution line delay	•Sequence optimization
6	•Reallocated from other plant	•FCFS overruled
7	•Time difference RDD change	•Time difference first promise

The first shortcoming is that *lead time promise is only given once a day*. Besides the fact that this can cause a slow responsiveness of first promise, it is also the root cause for the driver *time difference RDD change* [Nr 7 Late, Nr 4 Early]. When the customer does an RDD change after the scheduler import new orders to the schedule, the lead time promise will be based on the old RDD, since the lead time promise is determined at the end of the scheduling cycle. Constructing the schedule every time a new or changed order arrives can eliminate this problem. Besides the fact that this is time consuming, the third shortcoming shows that *human intervention is needed.* Customers can place and adjust orders 24 hours a day, seven days a week, so this would imply round the clock scheduling.

The problem of incorrect first manufacturing promises due to the once a day promise determination only occurs for changed orders, so new orders are not affected. Therefore a more feasible solution is to collect all orders that are changed during the day and make a first manufacturing promise based on a new schedule. A solution for the shortcoming itself can be achieved difficult within the current scheduling system, and therefore should be solved for the future ERP system.

The second shortcoming is that *not always the target earliness is available* in the schedule. This has impact on the drivers *sequence optimization* [Nr1 Late], *FCFS overruled* [Nr2 Late], *system bug weekend* [Nr3 Late] and *execution line delay* [Nr5 Late]. When less than the target earliness is given to an order, this means that less margin for rescheduling is available.

The solution for this is to give a first manufacturing promise that is always at least the target earliness later than the planned manufacturing due date. This will give every order the opportunity for rescheduling without immediately violating the first manufacturing promise. This logic is meanwhile already implemented and is one of the main improvements in delivery to first manufacturing promise performance.

The third recognized shortcoming is that *human intervention is needed due to timeslot scheduling*. This is the root cause for the drivers *time difference first promise* [Nr4 Late, Nr 7 Early] and *slot scheduling* [Nr3 Early], because in those cases human intervention is omitted. The drivers can easily be prevented by not omitting the human intervention. Meanwhile supply chain created awareness by the schedulers, about the impact of omitting human intervention. Therefore it is expected that the occurrence of these drivers is reduced.

The shortcoming itself can not to be solved without adjusting the scheduling software PSP, because it is build on slot scheduling and not capable to create a desired optimized schedule automatically. It is expected that no effort will be put in such adjustment in PSP, because of the new ERP system.

Besides the given shortcomings, some other causes are known about the drivers for Δ2 production alignment performance. Possible improvements for these causes will be discussed in the next section, if applicable.

Possible other improvements lead time promise

In this section possible other improvements to be more accurate in lead time promise are introduced, based on drivers for Δ2 production alignment performance. This will be done in the order of occurrence, first for late and then for early.

The first late, *sequence optimization*, will occur already less often, because of more margin for rescheduling. However, the lead time promise is given based on the detailed schedule. On the moment of lead time promise determination, not all information is known about the future state of the schedule. This is one of the arguments to use aggregate information, as proposed by Govers (2006). But when using the detailed schedule to determine the lead time promise, it only makes sense when the temporary sequence is optimal as well. This is particularly not the case at the Lexan plant.

Govers (2006) also mentioned the GAMS project, which would make it possible to optimize the sequence for the complete order set, taking into account penalties for due dates violation and changeover time. However, It proved that GAMS could not provide feasible solutions for the Lexan plant and finally the project is put on hold. The inability to schedule the orders on sequence is one of the main reasons why currently the target earliness is needed. However, it is not the only reason, as other reasons are insertions, remakes and uncontrollable extrusion throughput times.

The second late, which simultaneously is the sixth early, is *FCFS overruled*. As mentioned before, this is considered to be a commercial decision. The third late, *system bug weekend*, is already solved by adjusting the logic for that bug. The fourth late, *time difference first promise*, which also is the seventh early, is already solved by the improved awareness of the schedulers.

The fifth late, *execution line delay*, which refers to bumping of orders, is partially solved. Bumping refers to the fact that, due to line delay in the front of the order set, the orders in the back will be delayed as well. Besides more margin, also a better prediction model contributed to this improvement. However, there are still sources that cause orders to be bumped past the first manufacturing date. It is for instance still possible that due to bumping the margin for rescheduling becomes two days instead of a target earliness of 4 days, and then due to sequence optimization, the order becomes late.

The sixth late, *reallocation from plant,* is considered to be caused by superior powers and therefore not easy to predict. Finally for the seventh late and fourth early, *time difference RDD change*, no other improvement is expected besides the already mentioned shortcoming of PSP.

With regard to early only addition on arguments stated above is that the first and second early are considered to be commercial decisions. It is recommended to conduct research to the costs and benefits of this commercial decision in order to make a quantitative useful judgment. Is it wise, for instance to produce inventory products equal to a demand of three-quarter of a year, just to commit to the production targets?

W. Procedure PSP parameter settings

Preparation

1. Collect one year of history for a line;

   $aCOT_{PO}$ = Actual Changeover Time before startup PO
   aRT_{PO} = Actual Run Time of PO
   aQ_{PO} = Actual produced quantity of PO
   Q_{PO} = Requested quantity of PO
   $pCOG_{PO}$ = PSP planned Changeover Group for PO
   $pCOT_{COG}$ = PSP planned Changeover Time for group COG

Make sure to remove unreal data lines from dataset, so you can work with clean data.

Changeover Time

2. Sort all changeover groups COT_{COG} ascending

   $$pCOT_1 < pCOT_2 < pCOT_3 < \ldots < pCOT_M$$

This sequence should be respected, because it is used for sequencing purposes in PSP. This implicitly means that it might happen that the actual changeover time averages are not ascending.

3. Determine Changeover Group actual changeover time averages

   $$\overline{aCOT_{COG}} = \frac{\sum_{PO=1}^{N} aCOT_{PO}}{N_{COG}}, \text{ with all } PO \in pCOG_{PO}$$

4. Determine optimized planned Changeover Time per COG with the restriction from point 2.

   $$\min \sum_{COG=1}^{M} N_{COG} * \left| opCOT_{COG} - \overline{aCOT_{COG}} \right|$$
   where,
   $$opCOT_1 < opCOT_2 < opCOT_3 < \ldots < opCOT_M$$

5. Adjust parameters in PSP

   Set $pCOT_{COG}$ to $opCOT_{COG}$

Run Time

6. Check for time trend in run rate, based on *actual* production quantity

   $$aRR(aQ_{PO}) = \frac{aQ_{PO}}{aRT_{PO}}$$

When average run rate remains constant over the selected period, you can proceed. When there is a time trend in run rate, it should be understood why this time trend has happened and what the effect is on the PSP-parameter settings.

7. Determine minimum production quantity

a) Know the expected minimum production quantity; E(MPQ)
b) Take all PO's with requested quantity smaller then 0.5*E(MPQ), and determine the average actual produced quantity

$$MPQ = \overline{aQ_{PO}} = \frac{\sum_{PO=1}^{N} aQ_{PO}}{N}, \text{ with } Q_{PO} < 0.5 * E(MPQ)$$

8. Determine average actual run rate, based on *requested* production quantity.

$$\overline{aRR}(Q_{PO}) = \frac{\sum_{PO=1}^{N} \frac{\max(Q_{PO}, MPQ)}{aRT_{PO}}}{N}$$

9. Determine optimized RT_{PSP} settings RR and Q_{STD} for the RT_{PSP} formula with $I_Q = 1$ and $I_{RR} = 1$.

$$RT_{PSP} = \frac{(Q_{PO} * I_Q + Q_{STD}) * I_{RR}}{RR}$$

The optimized settings will be found via the following model, which is solved by using a branch and bound algorithm:

$$\min \sum_{PO=1}^{N} \left| \left(\frac{Q_{PO} + oQ_{STD}}{oRR} - RT_{MPQ}(Q_{PO}) \right) * TTE_{PO} \right|$$

$$\text{with } TTE_{PO} = \frac{\overline{aCOT_{PO}} + RT_{MPQ}(10.000)}{\overline{aCOT_{PO}} + RT_{MPQ}(Q_{PO})} = \text{Ten Ton Equivalent factor for PO [1]}$$

Resulting PSP parameter settings are oQ_{STD} and oRR, which are the optimized parameter settings for respectively Q_{STD} and RR of the RT_{PSP} formula.

Scenario's

MPQ scenario:
COT: result STEP 4
RT: RR: result STEP 8
Q_{STD}: result STEP 7

OPT scenario:
COT: result STEP 4
RT: RR: result STEP 9
Q_{STD}: result STEP 9