To get control of resources at Philips Uden
controlling when and how many resources to buy

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Controlling when and how many resources to buy

Graduation project at Philips Lighting Components Uden
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University of Technology, Eindhoven
Faculty of Technology Management
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Abstract

This report describes the problems with resource deficits at Philips Uden. Solutions are recommended to get better control of carriers, nozzles, and human resources. A study was done to find solutions for better inventory control and models are developed to get control of the various resources. These models include a joint optimisation of carriers and end product inventories and an optimisation of carriers, inventories and operators working in dayshift, 3 shifts, or 5 shifts. Precautions for the production consequences of development projects are recommended.

Executive summary

This document is the final report of the graduation project carried out at Philips Uden, from October 2004 to July 2005. Philips Uden produces two main product platforms, namely SON and CDM. Demand for these products has increased fast in the past years.

The project was executed according to the MEDIC approach. In the pre-MEDIC phase, the initial problem was stated and a metric was defined for the project. During the M-phase, the processes that affect the problem were investigated and described. The E-phase was in order to analyse the problems and to find the most important causes. In the D-phase, solutions were designed for the causes encountered during the E-phase. The I-phase contains a description of how those solutions must be implemented at Philips and the C-phase is in order to guarantee the benefit of this project.

Problem and assignment
The initial problem was stated as follows:

At Philips Uden incidents occur with resource deficits and since production volumes are growing rapidly it is expected that even more incidents will happen in the future. The incidents cost money because ad-hoc solutions are more expensive than structural solutions and because they lead to larger job dissatisfaction among employees.

The corresponding assignment was to give insight in the need for resources in the future, depending on mix, volume and growth with a mathematical tool and to set up a process to use this tool. The metrics defined for the assignment are the out-of-stock percentage of strategic carriers in the technical warehouse and the total value represented by those carriers.

The production process and the control of this process were described. Also, the current procedure for controlling resources was examined. Carriers and nozzles are product specific helping tools. Carriers are classified into four categories, namely routine carriers, bottleneck carriers, leverage carriers, and strategic carriers. The classification was made on the basis of the new carriers' delivery time and price.

It was decided to focus on product specific helping tools. The product specific helping tools under focus are bottleneck, leverage, and strategic carriers and nozzles.

The definite problem statement was:
There is no fixed procedure for the control of carriers and nozzle quantities so that:
1. *Production for certain items is stopped or delayed by a carrier or nozzle deficit too often*
2. *Extra costs are associated with ad-hoc solutions for deficits*
3. *Employees are unsatisfied because they feel that they have too few resources to do their job well and because they must find ad-hoc solutions for deficits*

The corresponding assignment was:
1. *Find causes for carrier and nozzle deficits and examine the contribution of each cause to the problem*
2. *Design solutions for the most important causes*

3. *(Partly) implement those solutions*

Causes
Seven groups of causes were found for the resources under the focus of this project. For some of these causes a solution was designed, for other causes precautions were recommended to prevent it from causing a resource deficit. The causes for which a solution was designed, were inventory accuracy causes, causes from unknown demand, and causes related to recording information. Causes, for which a precaution was recommended, are causes outside Philips, causes with a technical background, causes related to new equipment projects, and causes related to new product introductions. The impact of each cause group can be seen in the table below.

	Yellow: Inventory accuracy causes	Green: Causes from unknown need	Grey: Causes related to recording information	Orange: Causes outside Philips	Pink: Causes with a technical background	Blue: Causes related to new equipment projects	Purple: Causes related to new product introductions
Bottleneck carriers	20%	5%			5%	70%	
Leverage carriers		50%		50%			
Tiles	20%	15%	5%		10%	50%	
CDM moulds	25%	25%		20%		30%	
SON moulds		30%	30%	20%			20%
Nozzles	35%	30%	5%		5%		25%

Solutions
For inventory accuracy causes, four solutions are recommended to improve the accuracy of the SAP records of the technical warehouse. First, the access to the warehouse should be restricted to only 9 employees. Second, the inventory must be counted and corrected with the ABC-cycle count method. Third, the units of measure of some items in the warehouse must be changed so that the chance for mistakes decreases. Finally, the stock of articles that are not registered in SAP must be removed from the technical warehouse.

For the unknown need part, five different models are constructed. The first model is a simple tool to calculate the number of bottleneck and leverage carriers needed. Three models are constructed to deal with the demand for strategic carriers. The first is a model that calculates the number needed without the possibility of keeping inventories to deal with stochastic demand. The next model pursues a joint optimisation of carriers and inventories and the third aims to find an optimisation between carriers, inventories, and operators. For nozzles, a model is constructed that finds the best order quantities and order points, based on a (s,Q)-policy.

It is recommended to keep records of the number of carriers, to keep better information about the deterioration of carriers, and to construct a new file in which demand for nozzles is recorded and the components per nozzle.

The precautions recommended for new equipment projects are to include a member of production or planning into the project team and to adjust the requirements for passing a milestone in the project.

For new product introductions it is suggested that the carriers needed are specified in the first step of the project and that the tool developed for unknown need is used to calculate if new carriers should be purchased. Furthermore, it is recommended that the production department is more involved in new developments.

Implementation
Support for the solutions for the inventory accuracy matters was created among a project team that consisted of three employees that were all affected by the described solutions. It was described how the solutions must be implemented

Recommendations were made to evaluate the constructed tools for unknown need on a periodic base. It was recommended to assign employees to keep record of information that is needed as input for the models.

Amendments of the procedures for new equipment projects and new product introduction projects were proposed. These amendments were made officially by a project team initiated to improve project procedures of the development department.

Conclusions and recommendations
The metrics defined for this project were evaluated and it was found that the target was not reached yet. This is as expected, since the solutions and countermeasures were not implemented yet. It is recommended to keep track of the metric, even after the project to guarantee continuous improvements. It is also recommended to keep track of the inventory accuracy of the technical warehouse.

Preface

This report is the result of my master thesis project at Philips Lighting Components in Uden. This project is the final stage of my study Industrial Engineering and Management Science at the University of Technology in Eindhoven. This graduation project has been the most meaningful and interesting phase of my study for many reasons. Therefore, the project is a success for me already.

However, this success was not possible without the help of other people. First of all, my supervisor Tarkan Tan supported me from the beginning of the project. He was always very critical which was necessary to keep me sharp and keen. Dr. Flapper, my second supervisor, was always very enthusiastic and willing to help me further. I would like to thank them both for their efforts during my project.

I would also like to thank Marc Langelaar, my supervisor at Philips. Despite his busy activities, he always had some practical advice to help me further. I also thank the members of my project team, Martijn, Toin and Astrid for their time and enthousiasm. Moreover, my other 'colleagues' at Philips, especially Hilde and Elly, were always interested in my project, which supported me enormously to do a good job. Thank you all for this help!

My study would never have been possible without the support of my parents. Mum and dad, I want to thank you for all that you did for me in the past years. Without you, I would never have been where I am now. I also want to thank my brother and sister, Wouter and Leonieke.

A special word of thanks is for Erik, who was always there to support me during my dips and who remembered me that graduating is not the only thing that is important.

Finally, I would like to thank everyone else who was interested in my project and who made my study to a time to never forget. Thanks to all my friends, roommates, family, and team mates.

Aafke van Boekel
Uden, June 2005

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1. Company description

This chapter contains a brief description of the setting of the graduation project, namely the plant of Philips Lighting Components in Uden. In the report, some terms are used that are particularly common at Philips in Uden. An explaining glossary can be found at the end of the report.

Philips Uden is part of Philips Lighting Components. This division makes the components for various lamps sold by Philips Lighting. The business unit Lighting Components consists of nine factories and three staff departments. One of the factories is in Uden.

The plant in Uden produces ceramic tubes, called Poly Crystalline Alumina (PCA) tubes. PCA tubes are translucent ceramic envelopes used in High Pressure Sodium lamps and Ceramic Discharge Metal Halide lamps. [1] The most important customer of Philips Uden is Philips Turnhout. Philips Uden delivers 80% of its products to internal Philips customers; the other 20% is supplied to external customers all over the world.

The products of Philips Uden can be divided into four main product platforms, namely SON tubes, CDM tubes, white SON tubes, and Cermets. Pictures of SON and CDM tubes, the most important product platforms, are in Appendix 1. [1][2] Each product platform consists of several product groups.

At the plant in Uden work about 200 employees. Most of these employees work in production, but also the development department is important for Philips, since innovations are fast in the PCA industry. The organization chart of the plant is given in Appendix 2. [3]

2. Pre-MEDIC: Problem and assignment

This chapter gives a description of the first phase of the project. During this phase a decision was made upon the approach of the project; this approach is described in the first section of this chapter. Moreover, an initial problem definition and assignment was stated for the project.

2.1. Project approach

This graduation project was carried out with the MEDIC approach. This is a general method used at Philips to do improvement projects. The MEDIC approach has six different phases. During the pre-MEDIC phase the initial problem is defined and the purpose of the project is determined. The other phases are briefly explained in the table below. [4] A more extended explanation of the MEDIC approach is in Appendix 3.

Phase	Abbreviation of	Purpose
M-phase	Map & Measure	To understand the process
E-phase	Explore & Evaluate	To gain a quantitative understanding of where and how the process can be improved
D-phase	Define & Describe	To identify, describe and quantify the solution
I-phase	Implement & Improve	Implementation of the planned improvement
C-phase	Confirm & Control	A comprehensive control plan

Table 2-1 The phases in the MEDIC project approach

An important characteristic of MEDIC is that it uses a metric to measure the result of a project. A primary metric is set for the objective of the project and the secondary metric is to assure that progress on the primary really leads to business advantages and not to losses in another parameter.

2.2. Initial problem statement and assignment

The initial problem was stated after an interview with the company supervisor of the project, the production manager, and is as follows:

At Philips Uden incidents occur with resource deficits and since production volumes are growing rapidly it is expected that even more incidents will happen in the future. When a certain resource is short, this can delay production and customer orders may be delayed. Otherwise, the involved employees (both operators and other employees) have to find an ad-hoc solution to prevent delays in production. The incidents cost money because the solutions are more expensive than structural solutions.

The corresponding assignment was to give insight in the need for resources in the future, depending on mix, volume and growth with a mathematical tool and to set up a process to use this tool.

3. M-phase: Description of the processes

In the M-phase of the project, the initial problem is further examined. This chapter describes the production process and the control of this process. It also describes how resource capacity is controlled in the current situation. Finally, on the basis of these descriptions, a focus for the project is chosen and a definite assignment is formulated.

3.1. Production

3.1.1. Production process

First long tubes are processed on an extruder in the mixing department. Next, these tubes are cut into pieces and these pieces are assembled. The assemblies are heated in the elevator oven. If the assembly is complete it is heated in a high temperature oven to make it translucent. Finally, the products are checked and prepared for expedition.

At Philips Uden, products are classified into categories. First, there are the product platforms, which differ from each other in both composition and production process.. The most important product platforms at Philips Uden are SON and CDM tubes. SON products consist of only 3 components, whereas CDM products consist of 5 parts. Detailed descriptions of the production processes of the product platforms are given in Appendix 4.

Second, there is the classification into product types. A product type is a specific product that can differ from other products on for example size, wattage, or antenna. Later in this project, products will be classified into product groups based on the carriers used during the production process.

3.1.2. Control of the production process

The production process is planned on the basis of production orders. The production planner prepares these orders in weekly production schedules. The foremen take care that the orders are produced.

The main indicator of the performance of the production process control is the CLIP (Customer Line Item Performance) value. This value indicates how many order lines were fulfilled on time and in the right amount. An order line is the order from a customer for a specific product type on a specific date. An order line is defined to be tardy, when it is not delivered on the time that was originally agreed with the customer. The target for the CLIP value is 99%.

CLIP = (1 – (number of order lines delivered tardy/total number of order lines)) × 100%

3.1.3. Information for the production process

The planner plans on the basis of forecasts provided by customers. Every month, the customers give their forecasts for orders per month in the next year. The production planner adapts the forecast for the next month to a production schedule, based on safety stocks and current inventories. Doing this, the planner evenly spreads out production volumes over the weeks in a month as much as possible.

Most products are produced to stock, which means that a customer order can be expedited in one day. Orders are accepted by order acceptance in consultation with production planning.

Every week, there is a meeting for production, called production team (PT). This meeting is chaired by the production manager and attended by all group leaders (organization chart production, Appendix 2), production planning and order acceptance employees. In this meeting the current progress of production and the plans for the next week are discussed. This meeting is to assure a good information flow between planning and order acceptance on the one hand and production on the other hand.

3.1.4. Organization of the production process

Figure A 2-3 in Appendix 2 shows the production organization. The production and logistics manager is responsible for production, logistics, inventories, expedition, and planning of products produced by the production department. The group leaders are responsible for the production in their department and they direct the foremen.

The group leader production is responsible for the production processes of SON, CDM and white SON, except for the control process steps. The group leader end control is responsible for the end control department. The group leader cermets is responsible for the cermets department. The R&O department also falls under the responsibility of the production manager and is discussed in section 3.4.

3.2. Machines and human resources

At Philips, a tool, the Bouwens model, is used to get insight in the need for machines and human resources. The Bouwens model calculates the need for new machines for different growth scenarios. A scenario contains forecasts of demand for product platforms. The realistic scenario is the expectation of sales in the next years, made by the marketing & sales department. The optimistic scenario is simply 20% higher than the realistic scenario. The output of the model is the need for machines and human resources per year. The calculation of the optimistic scenario is used to buy machines because there will be idle capacity due to set-up times, peak demands, varieties in the product mix, etcetera.

The Bouwens model can be used to control human resource capacity, but another model is used for this purpose as well. This tool is based on productivity data in production for differing working schemes. Combined with the input from the Bouwens model, it shows the expected need for human resources.

Concluding, for capacity checks on machines and human resources, models are already in use. These models are not used for other resources because the models calculate the need on a long term (more than one year), and other resources can be purchased on a shorter term.

3.3. Helping tools

Helping tools are resources that are needed in some processes in the plant and that are re-used. These are product specific tools, which means that not all product types can be processed on the same helping tool. The helping tools under investigation are carriers and nozzles.

Carriers are tools that carry products during one or more steps of the production process. The flowcharts in Appendix 2 show which carriers are used during which steps. Carriers are classified into four different groups on the basis of their delivery times and prices as in Figure 3-1. [5]

The control of the four carrier groups and nozzles is described in sections 3.3.1 to 3.3.5.

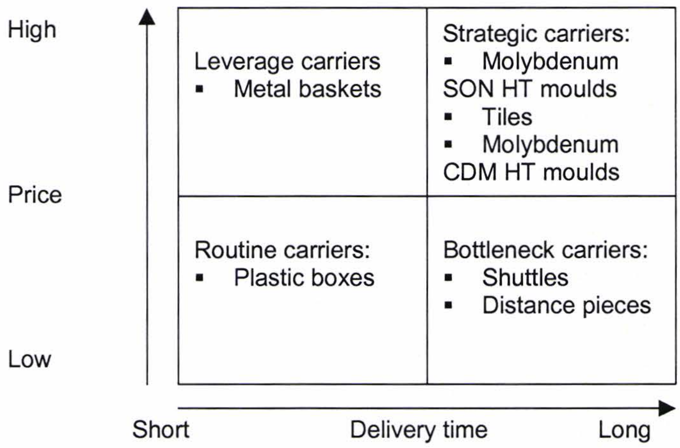

Figure 3-1 Classification of carriers

3.3.1. Routine carriers

The routine carriers are various sorts of plastic boxes with prices ranging from € 6 to € 25 and a delivery time between 2 and 8 weeks. Since routine carriers do not have a code in SAP, no stock or order data are available for these carriers. The price and delivery time information is based on interviews with the purchaser. When operators complain about having too few carriers regularly, the group leader discusses the deficits with the production manager and places an order at purchasing. Then the purchaser will order the necessary number of carriers.

Routine carriers are particularly used as storage carriers between process steps. Therefore, these carriers are not critical for production. It is possible to unload the boxes faster or to put more products in them.

3.3.2. Bottleneck carriers

Bottleneck carriers are shuttles and distance pieces. The average price of shuttles is € 16 and distance pieces cost € 0,22 plus a fixed transportation cost (€ 300) per order. The delivery time of shuttles and distance pieces is 10 to 16 weeks. [6]

Shuttles and distance pieces are kept at the production floor where the operators can use them. Spare carriers are kept on stock in the technical warehouse. If carriers are short, the team leader decides that carriers should be taken from this stock. An order point and a lot size are recorded in SAP. When the spare stock is below the order point, the purchaser orders the minimum lot size.

Shuttles

Shuttles are used to process products in the elevator ovens. There are small, medium, and large shuttles. The best option to cope with few shuttles is to put more products into one shuttle. It is also possible to use a medium or large shuttle for small products. These options make the shuttles more critical than routine carriers, but still not highly critical.

Distance pieces
Distance pieces are used in combination with tiles to process the CDM assemblies in the elevator oven. There are different sorts of distance pieces, ranging from a length of 25mm to 55mm. The most important option to handle deficits is to use a longer distance piece than required. The consequence of this option is that fewer products can be processed in one batch. The extent to which distance pieces are critical is the same as for shuttles.

3.3.3. Leverage carriers

The only leverage carriers are metal baskets, which have a delivery time of 4 weeks and cost € 48. Metal baskets are used as storage material for CDM rings. The procedure for these baskets is the same as the procedure for routine carriers. This means that these carriers do not have a code number in SAP nor are they stored in the technical warehouse.

The metal baskets are not critical for production, because they are not used in the production process itself and because it is possible to load more rings into one basket.

3.3.4. Strategic carriers

Strategic carriers are tiles, CDM HT moulds, and SON HT moulds.

Tiles
Tiles are used in the same processes as distance pieces. There are five sorts of tiles. The prices for tiles range from € 70 to € 317 and the delivery time is between 8 and 12 weeks. [6] Tiles are stored in the technical warehouse and are taken from this stock if they are necessary in production. For tiles, an order point and minimum lot size are defined in SAP, on the basis of which new carriers are ordered.

When tiles are short, there are no alternatives to cope with the deficits. Production volumes for CDM tubes will drop in the case of a deficit of a certain tile sort.

CDM HT mould components
CDM HT moulds are used to process the CDM tubes in the HT oven. The moulds contain several components made of molybdenum. This is shown in Appendix 6. [7] The price of components differs from € 13 to € 342. The cost of a complete mould is between € 3288 and € 4444. The average delivery time for components is between 8 and 14 weeks. The procedure for these components is the same as for tiles.

CDM HT moulds are also highly critical for production. There are no alternatives to process CDM tubes in the HT oven and the carriers cannot be loaded fuller.

SON HT moulds
SON HT moulds are used to process SON tubes in the HT oven and are also made of molybdenum. SON HT moulds are racks with honeycomb holes to put in the tubes. Appendix 7 shows a technical drawing of a molybdenum SON HT mould. [7] There are five sorts of SON HT moulds.

The price of SON HT moulds is about € 2500, dependent of the molybdenum price and the delivery time is about 26 weeks. The moulds are not kept on stock in a warehouse. All moulds are on a shelf from which they are used in production. There is no fixed procedure for buying new SON HT moulds. Mostly, the production manager decides on buying new carriers when he foresees an increase in its need.

For some products, it is possible to process them in another SON HT mould. However, this alternative should be used as a high exception, because it will affect the quality of the end products. Therefore, SON HT moulds are considered to be as critical as CDM HT mould components.

3.3.5. Nozzles

Nozzles are product specific tools in order to process long tubes on the extruders in the mixing department. Nozzles consist of a die, an extruding punch, and a punch holder. This is shown in Appendix 5. If a certain nozzle is not available, no production is possible for all product types that must be processed on this nozzle. Between 1 and 12 product types are processed on one nozzle.

For every nozzle, a compiled copy lies on a shelf for use in production. There is also one copy of the compiled nozzle in the technical warehouse so that a broken nozzle can be replaced immediately. Furthermore, one or more copies of each die and extruding punch are kept on stock in the warehouse.

Nozzles are taken from stock when a nozzle breaks down during production. Every week, a mechanic checks the dimensions and quality of the nozzles used in production. If necessary, this mechanic takes a punch or die from stock to replace the nozzle component. For the nozzles, punches, and dies, order points and minimum lot sizes are defined in SAP. When the stock in the warehouse is below the order point, new components are ordered, or a new nozzle is compiled.

3.4. Repair and maintenance

3.4.1. Tasks of the R&O department

The main responsibility of the R&O department is repair and maintenance. The mechanics control the quality of all production equipment, such as machines and helping tools. Also, the department repairs machines with a defect.

An important additional task of the R&O department is the control of the technical warehouse. The technical warehouse contains the stock of spare parts for all equipment in the factory. Some of the carriers are also stored in this warehouse.

3.4.2. Procedures technical warehouse

The operator that takes an item out of the technical warehouse writes the code number and name of the item plus the quantity taken on a list. The manager of the technical warehouse puts the records on the list into the SAP system. In SAP, an order point is recorded for each product. Every week, the purchaser runs an MRP run. This run generates a lot size for the products that are below its order points.

3.5. Focus and assignment

A focus for the project is determined based on the results of the M-phase. On the basis of this focus a definite assignment is formulated.

3.5.1. Focus of the project

The purpose of this project is to have enough resources available to be able to supply 99% of the customer orders on time. This purpose must be reached against the lowest total costs. It is tried to find an answer to the questions when to purchase resources and how many resources to purchase. The project will search for solutions that contain a timely and appropriate reaction on increased demand, deterioration and other developments within Philips Uden.

The main focus is on controlling the process of purchasing product specific helping tools. Currently, there is no fixed procedure for controlling these resources. For machines, the Bouwens model is used and a tool is being developed for the control of human resources. For product specific tools, however, no fixed control procedure is used at all.

The product specific tools that are handled are bottleneck, leverage, and strategic carriers and nozzles. Routine carriers are out of the focus of the project, because a routine carrier deficit will not cause a production stop. Besides, routine carriers did not cause any problems in the past two years.

3.5.2. Problem definition

The incidents mentioned above did not cause a missed customer order. However, it did cause stress and dissatisfaction among employees, because they had to find an ad-hoc solution or delay a project. It is possible that a customer order cannot be fulfilled because not enough carriers or nozzles are available. Therefore, the definite problem is stated as follows:

There is no fixed procedure for the control of carriers and nozzle quantities so that:

1. *Production for certain items is stopped or delayed by a carrier or nozzle deficit too often, which can result in missing a customer order*
2. *Extra costs are associated with ad-hoc solutions for deficits*
3. *Employees are unsatisfied because they feel that they have too few resources to do their job well and because they must find ad-hoc solutions for deficits*

3.5.3. Formulation of the assignment

The assignment is formulated as follows:

1. *Find causes for carrier and nozzle deficits and examine the contribution of each cause to the problem*
2. *Design solutions for the most occurring causes*
3. *(Partly) implement those solutions*

3.5.4. Project team

A project team was constructed that of employees from different disciplines. One of them is the mechanic of the R&O (repair and maintenance) department that is responsible for the technical warehouse, where the spare stock for most carriers is kept. The second employee involved is responsible for incoming material control and works as the foreman of the cermets department. This employee is of value for the team because she knows about all kind of problems in production. Moreover, she is responsible for the control of incoming resources. The third is the purchaser of the Philips Uden plant and can provide information on prices, lot sizes, and current procedures.

3.5.5. Metric

So, incidents with carrier deficits are a problem for Philips. It was tried to find a measurable value that corresponds to the number of deficits and to define this value as the metric. The metrics that compile the target for this project are defined as follows:

1. The percentage of time that the carrier stock in the warehouse equals zero

Some carriers are stored at two locations, namely at the production floor and in the technical warehouse. If more carriers are needed in production, the warehouse stock is used to supplement the stock in production. Carriers on the production floor do not return to the warehouse. When the stock in the warehouse is less than a certain order point, new carriers are ordered. As long as the stock of carriers in the warehouse is zero, no carriers can be taken from the warehouse to run production smoothly.

2. The total value of carriers in the plant and the warehouse

Of course it would be easy to decrease the out of stock situations by simply increasing the safety stocks. Then more carriers are kept on stock and that would cost more money too. So, the total value of carriers in the plant and the warehouse is important as well. This metric is calculated by multiplying the quantity of carriers by the value per carrier.

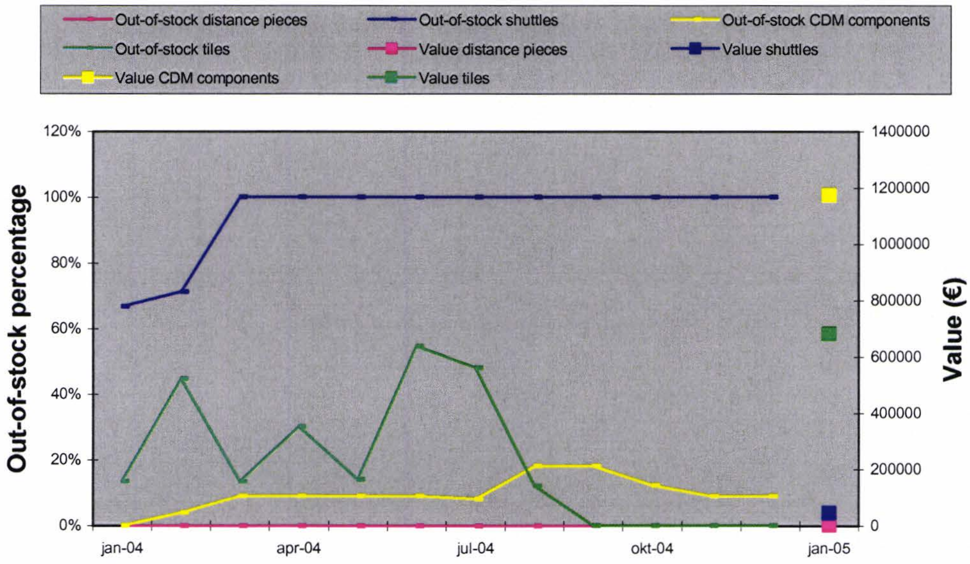

Figure 3-2 Value of the metrics in 2004

Value of metrics

The values of the metric are investigated for the carriers that have a spare stock in the technical warehouse. These are distance pieces, shuttles, tiles and CDM HT mould components. The out-of-stock percentages per month are shown in Figure 3-2. The total values were only recorded from January 2004 and are shown on the second vertical axis of Figure 3-2.

The target set for these metrics is to reduce the out-of-stock percentage of strategic carriers in the warehouse to 0%. The secondary metric is reported in order to monitor the increase in carrier value that is necessary to reach this target.

4. E-phase: Cause analysis

To find the causes for problems with helping tool deficits, a group interview was held with the project team. The advantage of this group interview was that the interviewees were stimulated by the others and that they hit upon ideas thanks to the contributions of the others. [8] During this session, the project team came up with causes for past incidents and ranked the causes on their occurrence rate in the last two years. Later, cause diagrams were constructed based on this session and the causes for resource deficits were grouped. Each group of causes got its own colour. On the basis of the brainstorm session, an estimation of the importance of each cause was made for each group of helping tools.

Since the focus of this project was on finding a timely and appropriate reaction on increased demand, deterioration and other developments, there are some causes that will not be solved by this project. However, precautions can be taken to prevent these things to cause deficits. Other causes can be solved within the scope of the project. The causes are grouped into causes that can be solved and causes for which precautions can be taken to prevent that they cause problems.

4.1. Causes for which a solution is designed

Inventory accuracy causes: Yellow
The stock information on items in the technical warehouse does not always correspond with the real stock situation. Since purchase orders are placed after an MRP run, problems occur when SAP indicates that there are still enough items in the warehouse while there is no stock left in reality.

Causes from unknown need: Green
Resources may also be short because it is unknown which quantity is needed. Then, orders are placed too late or order quantities are too small.

Causes related to recording information: Grey
Some information that is important to calculate the need for resources is not recorded. This holds for example for data about the number of resources on the repair shelf or data on the deterioration rate of carriers.

4.2. Causes against which precautions are taken

Causes outside Philips: Orange
These causes lay outside the focus of this project because they are influenced by factors outside Philips. The causes are mentioned in this report because they do influence the situation and can be constraining for the solutions designed for the various carriers. Examples of causes outside Philips are long delivery times of helping tools or fast increasing prices.

Causes with a technical background: Pink
The pink blocks represent causes that are out of the focus, because the technical background makes them a typical engineering problem. Furthermore, these causes are only minimally important because the technical problems form an exception to the normal situation.

Causes related to new equipment projects: Blue
At Philips, many projects are carried out to improve processes. Many improvements are realised by purchasing new equipment, but this new equipment also leads to a change in the production process. Those process changes can lead to an increase in the need for carriers either because a new carrier is needed or because more existing carriers are needed.

Causes related to new product introductions: Purple
Release projects are carried out to develop new products. These projects have consequences if demand for a certain carrier increases after the product release or if more helping tools are needed during the project.

4.3. Cause diagrams

For the different groups of carriers and for the nozzles, cause diagrams are constructed that can be found in Appendix 8. In the cause diagrams, the problem is most left and to the right are the causes for this problem. The most to the right are the root causes.

Table 4-1 gives an overview of the contributions of the various groups of causes to problems with deficits. The contribution percentages are estimations from the project group based on incidents in the past two years.

	Yellow: Inventory accuracy causes	Green: Causes from unknown need	Grey: Causes related to recording information	Orange: Causes outside Philips	Pink: Causes with a technical background	Blue: Causes related to new equipment projects	Purple: Causes related to new product introductions
Bottleneck carriers	20%	5%			5%	70%	
Leverage carriers		50%		50%			
Tiles	20%	15%	5%		10%	50%	
CDM moulds	25%	25%		20%		30%	
SON moulds		30%	30%	20%			20%
Nozzles	35%	30%	5%		5%		25%

Table 4-1 Summary of cause analyses

4.4. Focus for solutions

4.4.1. Bottleneck carriers

Bottleneck carriers are moderately critical to the production process. Solutions are designed to improve the inventory accuracy in the technical warehouse and precautions are recommended for new equipment projects to cause problems. For the unknown need a rough calculation method is presented, because the largest part of the problems is already prevented and because bottleneck carriers are not the most critical carriers.

4.4.2. Leverage carriers

Deficits for leverage carriers will not cause production stops, but these carriers are expensive. Therefore, it is important to have an idea of the quantity to be ordered and a solution is. Hence, the causes related to unknown need (40%) are solved by a rough estimation of the needed quantity. This will also partly prevent the causes outside Philips to cause deficits.

4.4.3. Strategic carriers

Tiles

Tiles are highly critical for the production process of CDM tubes. For this reason, a profound method is designed to calculate the number of tiles. In combination with solutions for inventory accuracy matters and recording information, this will largely prevent the causes with a technical background from causing deficits. For new equipment projects, some extra countermeasures are recommended to prevent problems in future.

CDM HT mould components

CDM HT mould components are also critical. A model is designed to calculate the number of components to be ordered. The inventory accuracy and the recording of important information are improved. This reduces the problems due to causes outside Philips and new equipment projects. Precautions are recommended to reduce the percentage for problems from new equipment projects even further.

SON HT moulds

SON HT moulds are very important for the production process of SON tubes. The solutions for unknown need are also to prevent causes outside Philips and new product introductions from causing deficits. The solution for recording information and some additional precautions for new product introductions will further reduce SON HT mould deficits.

4.4.4. Nozzles

Nozzles are extremely important for production at Philips Uden. Solutions are designed to handle the unknown need, inventory accuracy and recording of information. These solutions will prevent new product introductions and technical issues from causing problems in future.

5. D-phase: Solutions and precautions

During the D-phase solutions were designed for the causes that were found during the E-phase. In Section 5.1 solutions for inventory accuracy problems are presented. Section 5.2 describes models that are constructed to deal with unknown need. Section 5.3 presents the solutions for recording information. Section 5.4 describes precautions against the consequences of new equipment projects and precautions against the consequences of new product introductions are presented in section 5.5.

5.1. Inventory accuracy

First, the project team was asked to come up with possible solutions for improving the inventory accuracy. These solutions could also be improvements that did not solve the whole problem. Next, the advantages and disadvantages of these solutions were discussed and on the basis of this discussion the criteria for solutions were determined. Finally, the solutions were judged on the basis of these criteria and recommendations were based on this judgement.

First the possible solutions and the requirements are briefly explained. Next, the scores of the various solutions are presented and recommendations are made to improve on the current situation.

5.1.1. Possible solutions for inventory accuracy

The project team invented some of the solutions that are listed below. Other solutions were found by a benchmark on improving inventory accuracy in general, and inventory accuracy for spare parts in particular. [9][10]

Bar coding
Each item gets its own bar code that is scanned every time that a goods movement is made. The employee scans a sticker on the shelf and enters the quantity of the shipment into the bar code reader. This option will reduce the chance of entering the wrong code number, but it is still possible to enter the wrong quantity. The costs for installing a bar coding system are about € 3000. [11]

Moment related counting
Every time that a certain event occurs, for example when an item is taken from stock, the stock for the item is counted and if necessary the stock record is corrected. [10] This option assures that the most used items are counted most often; however, if an employee does not write down that he takes an item from the warehouse, the stock will not be counted.

The average number of goods movements out of the warehouse per week is 80. The time that will be spent on moment related counting is estimated as one minute per count.

ABC cycle counting
All items are classified into a certain category, A, B, or C. This classification is based on how long it will take before production stops when the item is out of stock. The stock for all items is counted periodically but the interval between counts differs per category. A-items are counted more often than B- and C-items. [9][10] This option assures that the most critical items are counted most often.

It was estimated that on average 80 items are to be counted every week. Next, a sample count of 80 items was carried out. It took one hour to do this sample count. Extra efforts are necessary to maintain the item's categories and for correcting the stock information.

Process cycle counting
The stock for all items is counted periodically and the counting interval is the same for each item. [10] This option does not guarantee a higher improvement on inventory accuracy for the critical items than for the non-critical items.

It is estimated that weekly 80 counts have to be made for this option; this will take one hour. Extra time is necessary for correcting information.

Restricted access
Only certain employees get access to the warehouse. [9] These employees are totally informed about the warehouse procedures and are therefore more capable of keeping the information accurate. Furthermore, it is easier to find out who made a mistake when something is incorrect.

The facility manager has calculated the costs for installing a system that restricts the access to the warehouse. The costs are € 5000. The efforts to maintain this solution are in serving employees that do not have access to the warehouse anymore.

Removing unregistered items
Currently, some items are only used by the R&O department and are not registered in SAP either. These items are simply reordered when stock gets visibly small. The warehouse manager is not responsible for these articles, so removing them from the warehouse will keep employees out of the warehouse. This contributes to a culture change of recording stock movements more carefully. Besides, this solution creates more space in the warehouse. Various options are possible for this solution, so that the costs are currently unknown.

Changing units of measure
At the moment, some items are always taken from stock by box or bottle but the record has to be registered by piece or gram. To decrease the chance for mistakes, the units of measure are changed so that they correspond to the quantity per record.

5.1.2. Evaluation of the solutions for inventory accuracy

When discussing the possibilities above, it was found that a culture change is the first requirement for improvement. None of the solutions will work if employees do not carefully record goods movements into and out of the warehouse. Therefore, a culture change is a necessary part of each solution.

The following requirements were determined for the solutions with the help of the project team:

- Increase in correctness of information in terms of inventory accuracy percentage
- Costs in euros of implementing the solution
- Efforts in man-hours to implement the solution
- Efforts in man-hours to maintain the solution

First, in cooperation with the project team the options got a score on a scale of 1 to 5 for the inventory accuracy. This score was based on a comparison of the various options and on the advantages and disadvantages of these options. The results are shown in Appendix 9. Next, the performance of the various options on the other criteria was evaluated.

Then, the combinations of solutions that added up to a score higher or equal to 11 on the inventory accuracy percentage were selected first. These are:

1. A combination of bar coding, ABC cycle counting, restricted access, removing unregistered items, and changing the units of measure (13)
2. A combination of ABC cycle counting, restricted access, removing unregistered items, and changing the units of measure (12)
3. A combination of bar coding, moment related counting, restricted access, removing unregistered items, and changing the units of measure (12)
4. A combination of bar coding, process cycle counting, restricted access, removing unregistered items, and changing the units of measure (11)
5. A combination of moment related counting, restricted access, removing unregistered items, and changing the units of measure (11)
6. A combination of bar coding, ABC cycle counting, restricted access, and changing the units of measure (11)

These solutions were compared to each other on the other criteria, as is shown in Table 5-1. It can be seen that the solutions with bar coding lead to high costs and high efforts, while bar coding got a low score on inventory accuracy. Therefore, the options 1, 3, 4, and 6 are also rejected and a choice is made between options 2 and 5. From these options, option 2 is the best as to accuracy and the costs and efforts are minimally higher than that for option 5. Concluding, option 5 is also rejected and option 2 is recommended.

However, it is unknown how expensive it will be to remove the unregistered items from the warehouse. Therefore, it is recommended to implement ABC cycle counting, restricted access and changing units of measure and to examine how many costs are associated with removing unregistered articles from the warehouse.

	1	2	3	4	5	6
Score on inventory accuracy	13	12	12	11	11	11
Costs in euros of implementation	€ 8.200 + ?	€ 5.000 + ?	€ 8.200 + ?	€ 8.200 + ?	€ 5.000 + ?	€ 8.200
Efforts of implementation (manhours)	88	48	81	81	41	78
Efforts of maintaining (manhours)	10	8	9	9	7	10
Number of positive side effects	4	4	4	4	4	2

Table 5-1 Comparison of best solutions for inventory accuracy

5.2. Unknown need

In the current situation, it is unclear which quantity of helping tools would be appropriate. Therefore, it is suggested to use a tool that can calculate how many helping tools to purchase. The helping tools are now classified into three categories, namely:

1. The bottleneck and leverage carriers
2. The strategic carriers
3. The nozzles

For the first category, one simple model is presented in section 5.2.1.

For strategic carriers, three models are presented. The first model in section 5.2.2 is a simple calculation of the number of carriers needed. The second model, section 5.2.3, is an extension to this model and aims to find a joint optimisation between carriers and inventories. In section 5.2.4, the third model pursues a joint optimisation between carriers, inventories and operators.

Finally, the model for nozzles in section 5.2.6 finds an order point and an order size for each nozzle component.

5.2.1. Simple model for bottleneck and leverage carriers

Bottleneck carriers have a long delivery time and are cheap in relation to other carriers, while leverage carriers have a short delivery time and are expensive. Deficits for those carriers will not cause tardy customer orders. For both sorts, the main focus is not to find an optimal quantity of carriers, but to have a simple model that helps to decide on the number of carriers to buy.

Description of the model

A simple model is constructed to evaluate how many carriers are necessary. The number of carriers needed (*n*) is calculated by using the average sales per week (S) for which the carrier sort is needed plus a safety factor, and the number of products the carrier can take (*q*).

Decision variable	
n	Number of carriers needed
Parameters	
S	Average sales per week in number of end products
q	Number of end products in one carrier

Equations

For leverage carriers, the safety factor is lower than for bottleneck carriers, because it is easier and faster to order new leverage carriers. Moreover, it is cheaper to have a surplus of bottleneck carriers. According to the group leader production, the current number of SON shuttles, distance pieces, and metal baskets is appropriate for the actual production volumes. It was found that the current number of carriers could be approached via a safety factor of 20% for the bottleneck carriers and a safety factor of 15% for leverage carriers.

Equation 1: $n = 1{,}20 \cdot S / q$ for bottleneck carriers

Equation 2: $n = 1{,}15 \cdot S / q$ for leverage carriers

SON shuttles

SON shuttles are used in the elevator ovens for assembled SON products. There are three different sorts of shuttles, namely small, medium and large. On average, those shuttles carry 140 end products. Currently, there are in total 2820 SON shuttles.

Distance pieces

Distance pieces, bottleneck carriers as well, are used in the assembly steps of CDM products. Distance pieces carry on average 80 products, but are used during 4 steps for each end product, which can be seen in the flowchart for CDM products in Appendix 4. Therefore, the volume per distance piece corresponds to 20 end products. There are five different sorts of distance pieces, namely distance pieces of 25mm, 30mm, 40mm, 45mm, and 55mm. On total, it is estimated that there are now 13.100 distance pieces.

Metal baskets
Leverage carriers are metal baskets that are used for storage of CDM rings. A metal basket carries on average 1.800 rings and each end product needs two rings, so that 1.800 rings correspond to 900 end products. Currently, there are 250 metal baskets.

Quantity per type
The total number per carrier sort can be calculated by Equation 1 and Equation 2, but for the SON shuttles and distance pieces it is not yet determined how many of each type are needed. To calculate this, the current distribution over the sorts is combined with the total number of carriers needed. The number per carrier sort is rounded up to tens to be on the safe side per carrier type.

Inputs and results
Every year, a production employee must count or estimate the number of leverage and bottleneck carriers present in the factory. Then, with the method described above, one can decide to purchase more carriers.

For metal baskets and distance pieces, the average CDM sales are input. From May 2004 to April 2005, the average CDM sales per week were 214.752 CDM tubes. For shuttles, the average SON sales are input. The average SON sales per week from May 2004 to April 2005 were 327.590 products per week.

Since bottleneck carriers are not expensive but critical for production, it is recommended to keep spare shuttles and distance pieces on stock in the warehouse. Currently, an order quantity and order point is defined for both carrier sorts. It is recommended to keep the order quantity at the same level. This quantity is defined based on optimal order quantities as to quantity discounts, packaging volumes, etc. The order point, however, should be changed to 10% of the calculated needed quantity. If this 10% turns out to be too low or too high, it can be changed. The values of the metric can be used to judge on this.

Leverage carriers (metal baskets) are not kept on stock until now and this is not recommended either, because the delivery time is short (4 weeks) and metal baskets are not critical for production. The number of leverage carriers can be evaluated once a year. If the group leader production in between thinks that more metal baskets are necessary, he can ask the controller to evaluate the model already.

The described model is evaluated for the current situation. The results are in Appendix 11. It can be seen that the calculated needed quantity is 274 for metal baskets, 2.808 for SON shuttles and 12.885 for distance pieces. As expected, no extra carriers have to be ordered now. Only, the order points for distance pieces and SON shuttles must be changed. The new order points are also in Appendix 11.

5.2.2. Simple model for strategic carriers

At Philips Uden, it is not tried to find a joint optimisation of capacity and inventories. Therefore, it is first calculated how many carriers are needed when production is equal to a safety factor times the forecasted demand. An advantage of this model is that it is easy to understand and that therefore the outcomes will be more acceptable. A second reason to use this model might be that the plant is reviewed on the basis of its inventory levels.

Description of the model

The purpose for tiles, CDM HT moulds, and SON HT moulds is to be able to supply 99% of the customer orders on time. This is measured by the CLIP performance. The model will calculate how many carriers of a certain product group must arrive in a certain period ($C_i(t)$), given a forecast and a safety factor for this forecast. So, the decision variable is $C_i(t)$.

Although not all variables are declared yet, an alphabetic list of the notation used for variables is given below. An overview of the notation used for parameters can be found in Appendix 10.

Decision variable	
$C_i(t)$	Number of carriers of carrier group *i* delivered in period *t*
Variables	
$A_i(t)$	Number of carriers of carrier group *i* available at the beginning of period *t*
$n_i(t)$	Number of carriers of carrier group *i* needed in period *t*
$P_i^{\max}(t)$	Production per week in number of end products for product group i in period *t*
$s_i(t)$	Safety factor added to forecasts for period *t* for product group *i*
$X_i(t)$	Number of carriers of carrier group *i* thrown away during period *t*
$y_i(t)$	Binary variable, 0 if $C_i(t) = 0$, 1 if $C_i(t) > 0$

The model is evaluated over a total period of 4 years. The delivery time of new strategic carriers is at most 6 months. The total period of evaluation should then be at least 1,5 years, since during the first half year no new carriers can be planned to arrive anymore. Furthermore, the carrier orders planned to arrive after the first half year may have to be combined with each other. However, a period of 4 years is chosen to be able to show the deficits in future. This can be used for decisions to put efforts into process changes.

The unit of one period is a week, because months have different lengths at Philips. A week always has the same length, so that sales numbers correspond to the volumes that have to be produced per day. So t = 1,2, ..., T, where T = 200, because there are 50 production weeks per year. The product types and carriers are divided into groups so that it can be calculated which volumes are processed on a certain carrier sort. The groups are represented by indices i, where: $i = 1,2,\dots, N$.

Assumptions

1. Resources, other than carriers, are always available to a certain maximum amount of aggregate production. This assumption is justified because the purpose of the model is to find the best carrier quantity.
2. The throughput-times of each carrier group are equal to the weighted average of the throughput-times for the carrier group in the last year. This assumption is justified because the throughput-time in the past year is a possible target, since it was reached in the past year. The actual throughput-times will sometimes be higher, but then it will be possible to reduce it if more carriers are needed.
3. The average number of products in a carrier is equal to the number of products per carrier averaged over the product types in a group. This assumption holds because the number of products per carrier group is the

weighted average over the product types in the group, based on the sales per product type in the last year.

4. The carriers are only loaded with a certain loaded ratio because batch sizes do not correspond to the carrier capacities.
5. An addition or decline of carriers always takes place at the end of a period. For additions, this assumption is justified because the period of one week is short compared to the delivery time of the carriers. For declines, the number of declines per period is insignificant.

Forecasts

For strategic carriers, the forecast that is used for production planning is not suitable because this forecast is only for one year in advance and the model is evaluated over a longer period. Moreover, these forecasts are for product groups that do not correspond to the carrier types. Therefore, the forecast per product group is based on historic sales data, namely sales per month in 2001, 2002, 2003, and 2004.

Because months have different lengths, the sales quantities are divided by the number of weeks in a certain month, which makes the sales volumes comparable to each other. It is no violation to the validity of the forecast because the planner spreads sales volumes evenly over the weeks in a month. So, the input is the average sales volume per week in a month.

Five different forecasting methods are evaluated by comparing the forecasts to the sales data of 2001, 2002, 2003, and 2004. Based on the methods described in literature, the following methods are evaluated:

1. Moving average method [13]
2. Linear regression method [14]
3. Simple exponential smoothing method [13]
4. Linear exponential smoothing method [13]
5. Linear and seasonal exponential smoothing method [13]

The performance of these methods was evaluated on the basis of the mean square error. [13] For each product group, the least mean square error was found with the linear regression method. Therefore, the forecasts for periods t = 1 ...T for each product group are found by using linear regression on the sales data of the previous four years.

These forecasts are forecasts for the average sales volumes per week in a certain month. At Philips, there is a fixed schedule for the number of weeks in a month. This schedule (Table 5-2) is also used for this model. The forecast for the demand in a week is represented by $F_i(t)$.

Month	Number of weeks	Month	Number of weeks	Month	Number of weeks
January	5	May	4	September	4
February	4	June	4	October	5
March	4	July	4	November	4
April	5	August	3	December	4

Table 5-2 The fixed schedule for weeks per month

Equations

The actual demand in a period will not be equal to the forecast. The purpose of the model is to have enough resources to be able to fulfil 99% of the customer orders.

Therefore, a safety factor $s_i(t)$ is added to the forecast. The carrier capacity must be large enough for this production volume ($P_i^{\max}(t)$).

Equation 3: $P_i^{\max}(t) = F_i(t) + s_i(t)$

This safety factor is related to the errors of the forecasts. The distribution of the error of the linear regression method is investigated by comparing the forecasted values of the previous four years to the real sales volumes. This means that for each type the sample size for the hypothesis test was 48. The hypothesis was that the errors were normally distributed. For all types, this hypothesis could not be rejected with 90% certainty. Also, the normal probability plots showed that the errors were likely to be normally distributed. Therefore, the assumption that the errors are normally distributed is valid. [14]

A factor *k* is introduced to assure that the safety factor is able to deal with 99% of the customer orders.

Equation 4: $\begin{array}{l} p_{\geq}(k) = 0{,}01 \\ k \approx 2{,}33 \end{array}$ [14]

Although the errors of the forecasts on historic data were time independent, it is likely that the errors of the forecasts will be higher when demand is higher. For this reason, the safety factor is multiplied by the coefficient of variation and the forecast for a period. The coefficient of variation is the division of the standard deviation and the average demand.

Equation 5: $s_i(t) = k \cdot cv_i \cdot F_i(t)$

The solid lines in Figure 5-1 represent the actual demand for the various carrier groups (before April 2005) and the forecasts for these products, $F_i(t)$ (from April 2005). The dotted lines are the figures that are actually used for the calculation of the number of carriers needed, $P_i^{\max}(t)$.

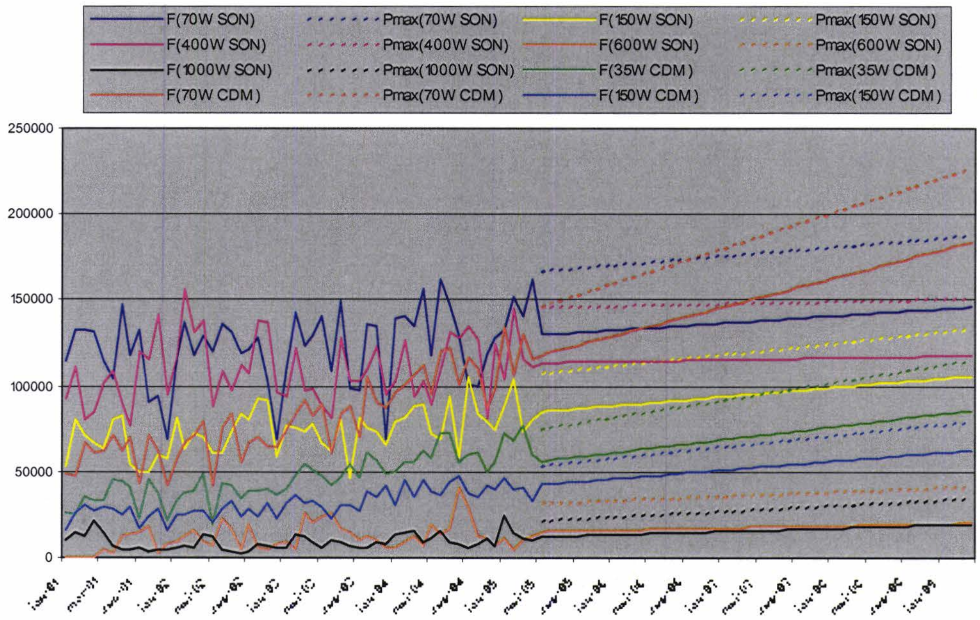

Figure 5-1 Actual demand, $F_i(t)$ and $P_i^{\max}(t)$ per carrier group

Production for product group *i* in period *t* is constrained by the number of carriers. The needed number of carriers of a carrier group *i* in period *t* ($n_i(t)$) depends on:

1. The production for product group *i* in that period, $P_i^{\max}(t)$
2. The loaded ratio of the carrier (f_i), this is the average number of carried products divided by the number products that can be carried by a carrier
3. The number of products (q_i) that can be carried by one carrier
4. The maximum number of times that a carrier can be used in a week ($U_i^{\max}$)).

Equation 6: $n_i(t) = \dfrac{P_i^{\max}(t)}{f_i \cdot q_i \cdot U_i^{\max}}$

The number of times that an available carrier can be used ($U_i^{\max}$) depends on the throughput-times of the carriers, λ_i. The throughput-times are recorded in days at Philips, so that the number of maximum usages per carrier per week is calculated as:

Equation 7: $U_i^{\max} = \dfrac{7}{\lambda_i}$ for all t = 1,...T

To determine how many new carriers must arrive, the needed number is compared to the number available $A_i(t)$. There is a minimum lot size $C_i^{\min}$ for carriers, so the number of carriers purchased must either be zero or at least the minimum lot size. For this reason, a binary variable $y_i(t)$ is introduced.

Equation 8: $\begin{cases} y_i(t) = 0 & \text{if} \quad n_i(t) - A_i(t) \leq 0 \\ y_i(t) = 1 & \text{if} \quad n_i(t) - A_i(t) > 0 \end{cases}$

$C_i(t)$ represents the new carriers delivered in a certain period.

Equation 9: $C_i(t) = \max\left[C_i^{\min} \cdot y_i(t); n_i(t) - A_i(t)\right]$

The number of carriers available at the beginning of period *t* of carrier group *i* depends on:

1. The number of new carriers that has been delivered in period *t*-1 $C_i(t-1)$;
2. The number of carriers that went broken in period *t*-1 $X_i(t-1)$;

Equation 10: $A_i(t) = A_i(t-1) + C_i(t-1) - X_i(t-1)$

The breakdown rate differs per carrier sort and therefore the formula presented here is a general description of the relationship between carriers that break down and carriers currently available $A_i(t)$ and the average usage of carriers in a period.

Equation 11: $X_i(t) = \dfrac{P_i^{\max}(t)}{q_i \cdot a_i} + b_i \cdot A_i(t)$

In this formula, a_i is the lifetime of a carrier expressed in number of uses and b_i is the deterioration percentage of carriers that break from other causes than the end of lifetime in uses. The average number of times that carriers are actually used is calculated by dividing the production for product group *i* in period *t* through the average number of products carried by one carrier. An analysis of the parameters a_i and b_i for the various carriers is in Appendix 12.

Specifications for SON HT moulds

If SON HT moulds break, they are not thrown away, but are placed in the repair shop. The R&O department repairs those carriers and throws away the carriers that cannot be repaired anymore. It is assumed that every 6 months the R&O department does this kind of repair work for all carriers in the repair shop. From historic data it is found that 50% of the carriers are taken back into production and the other 50% is thrown away.

This means that all broken carriers go into a repair shop. Two new variables are introduced that represent the build-up of carriers in repair and carriers leaving repair again. $R_i(t)$ is defined as the number of carriers present in the repair shop at the end of period t. $Y_i(t)$ is the number of carriers that leave the repair shop at the end of period t.

Equation 12: $R_i(t) = R_i(t-1) + X_i(t-1) + Y_i(t-1)$ for all t

Equation 13: $Y_i(t) = R_i(t-1)$ for t = 25, 50, 75, 100, 125

Equation 14: $A_i(t) = A_i(t-1) + C_i(t-1) - X_i(t-1) + 0{,}5 \cdot Y_i(t-1)$ for all t

Specifications for CDM HT moulds

CDM HT moulds consist of several parts. An overview of the parts per mould is in Appendix 6; an overview in Appendix 13 shows to which group(s) each of the components corresponds. Now, for each component a separate evaluation of the need is made.

Specifications for CDM tiles

CDM tiles are always processed in loops so that the throughput-time is not the only parameter that influences the number of tiles needed. It is calculated how many tiles are in one loop. The production volume is equal to the number of loops times the number of products per loop. The number of loops per week is a fixed number B. The variable $\tau_i(t)$ is defined as the number of tiles per loop in period t for tile type i.

Equation 15: $$\tau_i(t) = \frac{P_i^{\max}(t)}{B \cdot q_i}$$

The number of tiles needed is calculated by the number of tiles per loop and the number of loops that is in progress at the same time. In Equation 16 the term between brackets is rounded up to get an integer number of loops.

Equation 16: $$N_i(t) = \tau_i(t) \cdot \left\lceil B \cdot \frac{\lambda_i}{7} \right\rceil$$

Input variables

For this model, forecasts are made on the basis of the sales data per product group over the previous four years. These data are in the sales database of the marketing and sales department [9].

For SON HT moulds, deterioration and lifetime data were based on the data of 10 test moulds [13]. The Factory Engineering department provided these data. No more than 10 test moulds were tested, so that no more data were available. Appendix 12 shows this analysis. For CDM HT moulds, the foreman of the end control department made an estimation of the number of components breaking per week. For CDM tiles, the foreman of the CDM department made the same estimation for each tile sort.

The number of products per mould is in SAP for each product code number and can be found in the routing of the product [16].

Throughput-times for SON and CDM HT moulds are recorded in a database, in which operators record per product code number when a specific step is finished [17]. For tiles the throughput-times are not recorded. Therefore, these throughput-times are estimated on the basis of a detailed planning for the CDM production department. [18] This detailed planning is made by the project leader that is responsible for extending the capacity of the CDM department.

The current number of carriers available was not recorded until now. For this reason, all carriers have been counted. The current numbers are in Appendix 13 as well. The current number of carriers is recorded in special files in future. [19]

Results

It can now be calculated how many carriers must arrive in which periods to be able to fulfil 99% of the customer orders. Table 5-3, Table 5-4, and Table A 13-5 show the arrivals in one year from now for the three sorts of strategic carriers.

To come to good decisions of how many carriers to buy, it is important that the forecasts used as input are validated. If one is not sure that the forecasts display the realistic situation, the forecasts can be adjusted and the consequences for the carrier need can be evaluated. On the basis of such sensitivity analyses, the planning meeting can make a well-considered decision on the number of carriers to buy.

This decision should also include a quantity discount consideration. The model just calculates when new carriers should arrive and does not calculate the best quantity to purchase. This is not possible, because quantity discounts differ yearly and are strongly dependent on constraints outside Philips.

Arrivals for new SON HT moulds

Figure 5-2 shows how many SON HT moulds are expected to be available in the next four years and how many are necessary. It can be seen that the available number increases when repair work is done (every 25 weeks) and when new carriers arrive. The last event occurs when the number necessary becomes more than the number available.

Combining orders for SON HT moulds

Table 5-3 shows the SON HT moulds that should arrive in one year from now. For 600W and 1000W moulds, it is probably better to combine orders and to let arrive 30 600W moulds and 37 1000W moulds in period 1. This is evaluated by comparing the price increase of molybdenum to the holding costs for carriers. The price increase for molybdenum is on average equal to 0,4589% per week. The holding cost percentage for carriers is 0,152% per week.

Period	Month	Number of 600W moulds arriving	Number of 1000W moulds arriving
1	May 2005	10	17
2	May 2005		10
9	July 2005	10	
13	August 2005		10
25	November 2005	10	10
46	April 2005		10

Table 5-3 Arrivals for SON HT moulds in one year from now

This means that it is always the best to buy carriers early. If one would be sure that all carrier purchases given by the model are necessary, it is the best to buy them at once. However, uncertainty is high and it might be possible that the carrier purchases are not all necessary because of process changes or other circumstances.

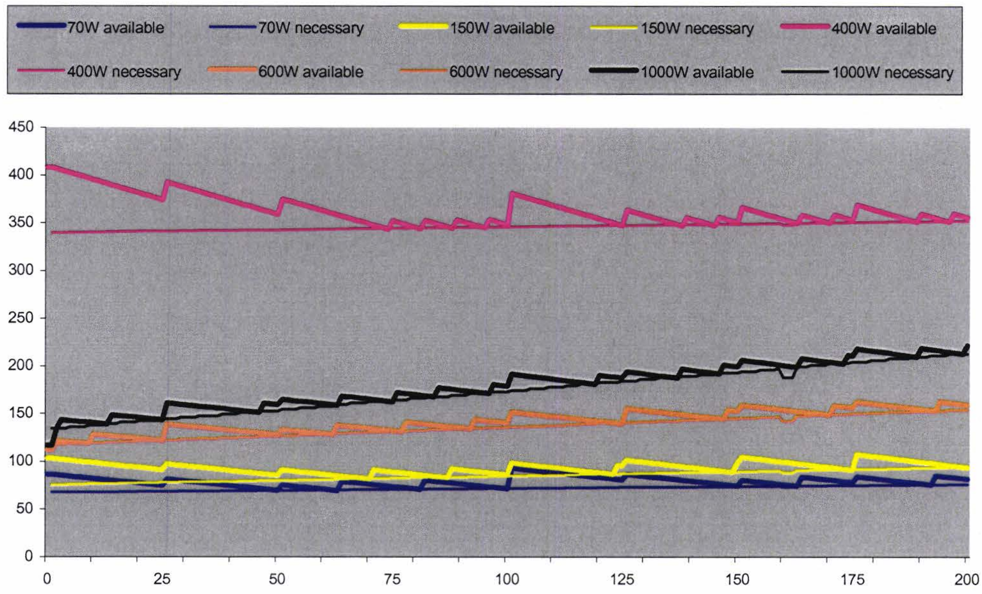

Figure 5-2 Available number of SON HT moulds compared to necessary number of carriers

Arrivals for new CDM HT mould components

Figure 5-3 shows the available and necessary CDM HT mould components in the next 4 years. It is clear that the available number increases when new carriers because the necessary carriers are more than the available carriers.

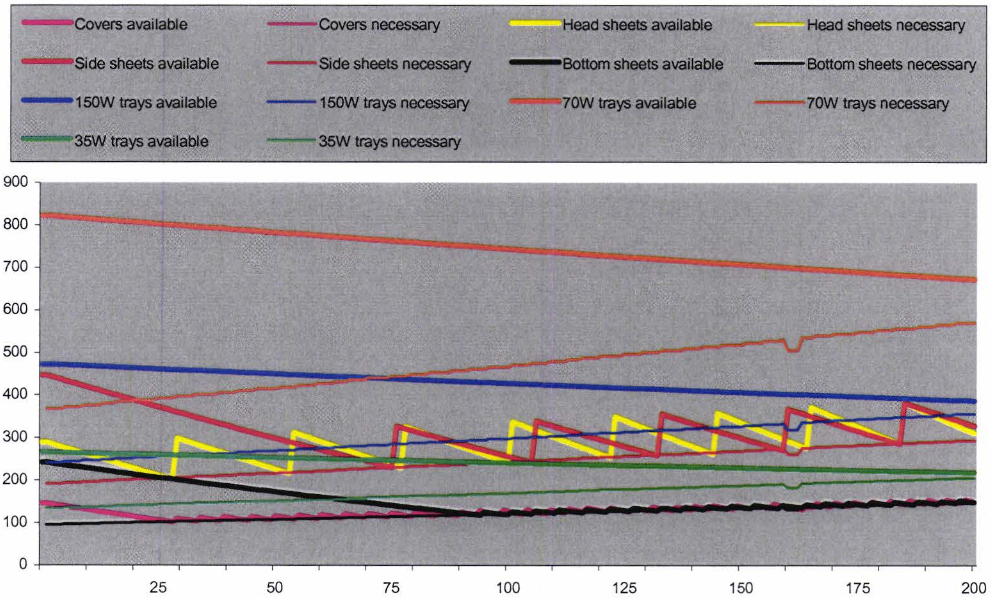

Figure 5-3 Available number of CDM HT mould components compared to necessary number of carriers

Table 5-4 shows how many CDM HT mould components should arrive in one year from now. However, it could be possible that expected demand is higher than the forecasts on the basis of historic data. If the planners meeting thinks that this is the case, the model can be evaluated for a higher demand. For CDM HT components, this is done for a demand 10% higher than the forecast. The results are in Table 5-5. This table shows that, if demand were indeed expected to be higher, it would probably be better to let arrive covers and head sheets earlier.

Period	Month	Number of covers arriving	Number of head sheets arriving
28	November 2005	10	100
33	January 2006	10	
38	February 2006	10	
44	March 2006	10	
49	April 2006	10	

Table 5-4 Arrivals for CDM HT mould components on basis of forecasts

Period	Month	Number of covers arriving	Number of head sheets arriving
21	October 2005	10	100
26	November 2005	10	
31	December 2005	10	
36	January 2006	10	
41	February 2006	10	
46	April 2006	10	

Table 5-5 Arrivals for CDM HT mould components on basis of forecasts plus 10%

Arrivals for new CDM tiles

The expected available and necessary numbers of tiles are in Figure 5-4. The arrivals for CDM tiles in one year from now are in Appendix 13, Table A 13-5. Also for tiles it is probably better to combine orders. The purchaser can give advice on this issue.

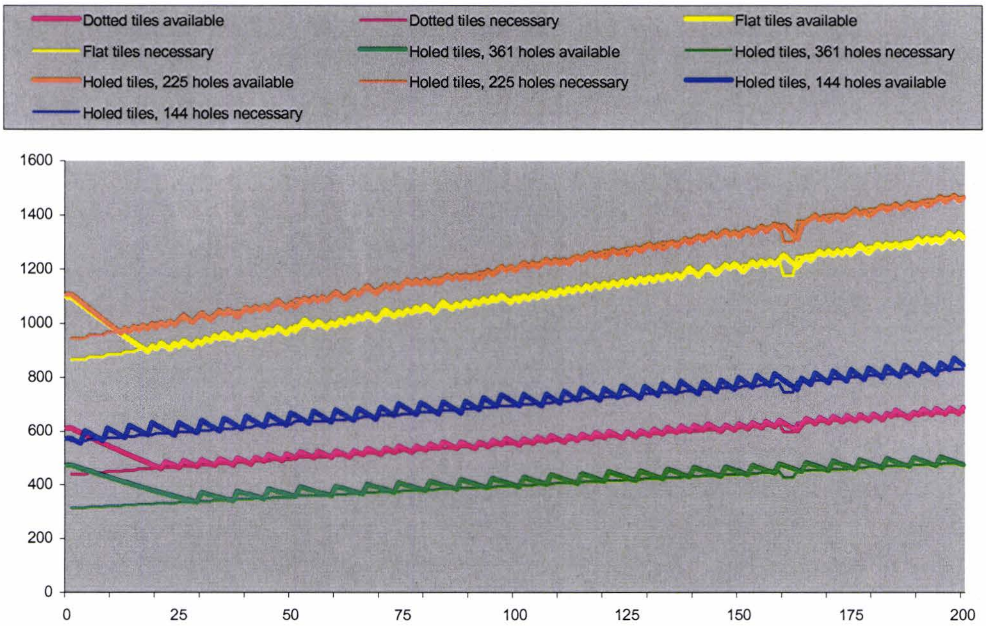

Figure 5-4 Available number of CDM tiles compared to necessary number of carriers

Performance of the model
To evaluate if the target is reached, forecasts for 2004 are made with sales data over 2001, 2002, and 2003. The standard deviations of the errors over the period 2001-2003 are used to calculate the safety factor. The production volumes for 2004 are then calculated with Equation 3 and Equation 5 and these amounts are compared to the real sales data in 2004.

To calculate the performance of the model, the actual sales are represented by $S_i(t)$. If sales were higher than $P_i^{\max}(t)$, the difference between $S_i(t)$ and $P_i^{\max}(t)$ was divided by the sales in a period to find the CLIP performance for a period for a specific product group. The CLIP performances per period and per product group were averaged to find the average CLIP performance.

Equation 17: $$CLIP_i(t) = 1 - \frac{\max\left(0; (S_i(t) - P_i^{\max}(t)\right)}{S_i(t)}$$

Equation 18: $$CLIP_{average} = \frac{\sum_{t=1}^{T}\sum_{i=1}^{N} CLIP_i(t)}{T \cdot N}$$

The average CLIP performance was calculated for the three strategic carrier sorts. For SON HT moulds, the calculated average CLIP in 2004 was 99,79% and for CDM HT mould components as well as for CDM tiles it was 100%. This means that for 2004 the model performed even better than the target, which was 99%.

5.2.3. Joint optimisation of inventories and carriers

In this extended model, costs are a joint function of holding inventory of end products and buying and holding carriers. The objective is to minimize total costs by deciding on production volumes and the number of carriers to purchase. The purpose is to minimize costs while fulfilling 99% of demand as agreed with the customer.

Assumptions
Two additional assumptions are made that concern inventory and carrier costs.

6. The value of the products in a group is equal to the average value of the products in this group. This assumption is valid because standard deviation is less than 0,5 of the average value for each product group (Appendix 14). The value of the products is equal to the material costs plus the costs that were made to process this product in all previous steps (this includes labour costs and overhead).
7. Carrier costs are the sum of the costs of buying new carriers plus the costs for keeping the carriers on stock. This is true because no more costs are associated with carriers. Deterioration costs are handled by the costs of buying new carriers.

Description of the model
The objective of the model is to minimize the costs for holding inventory and buying and holding carriers. The decision variables are the production volumes for product groups *i* in period *t*, $P_i(t)$, and the number of carriers of carrier group *i* that must arrive in period *t*, $C_i(t)$. An overview of the notation of the variables is given below; the parameters used in this model are defined in Appendix 10.

Decision variables	
$C_i(t)$	Number of carriers of carrier group *i* delivered in period *t*
$P_i(t)$	Production in number of end products per week for product group i in period t
Variables	
$A_i(t)$	Number of carriers of carrier group *i* available at the beginning of period *t*
$I_i(t)$	Inventory in number of end products of product group *i* at the end of period *t*
$p_i(t)$	Price in euros of new carriers in carrier group *i* in period *t*
$SS_i(t)$	Safety stock in number of end products for products in product group *i* in period *t*
$X_i(t)$	Number of carriers of carrier group *i* thrown away during period *t*
$y_i(t)$	Binary variable, 0 if $C_i(t) = 0$, 1 if $C_i(t) > 0$

Equations

The inventory costs depend on the inventory in a period t ($I_i(t)$). The carrier costs are influenced by $C_i(t)$ and $A_i(t)$, where $C_i(t)$ is the number of carriers of a certain carrier group delivered at the beginning of period *t* and $A_i(t)$ is the number of carriers available for production during period *t*. The holding cost percentage for end products is h_1. Carriers have a holding cost percentage h_2. The value of products in a product group is v_i and the price of one carrier in period *t* is $p_i(t)$.

The objective of the model is to minimize total costs. The decision variables are the number of carriers that arrive in a certain period and the inventory to hold for end products. This is represented by the following objective function:

Equation 19: $$\min \sum_{i=1}^{N} \sum_{t=1}^{T} \left[h_1 \cdot v_i \cdot I_i(t) + p_i(t) \cdot \left[C_i(t) + h_2 \cdot A_i(t)\right]\right]$$

The physical inventory of end products for a product group *i* at the end of period *t* is a function of the inventory that was left from the previous period, the production in period *t* ($P_i(t)$), and the demand in period *t* ($D_i(t)$).

$$I_i(t) = I_i(t-1) + P_i(t) - D_i(t)$$

Production for product group *i* in period *t* is constrained by the number of carriers. The maximum production for a product group *i* in period *t* related to carriers depends on:

1. The number of products carried by one carrier (q_i)
2. The loaded ratio of the carrier (f_i)
3. The number of carriers available of a carrier group ($A_i(t)$)
4. The number of times that a carrier can be used ($U_i^{\max}$).

Equation 20: $$P_i(t) \le q_i \cdot f_i \cdot A_i(t) \cdot U_i^{\max}$$

New carriers have a delivery time that is more than one period. This means that in the periods from now until the end of the delivery time LT_i only those carriers are delivered that were already ordered when the model is evaluated. The orders for carriers are represented by $x_i(t)$.

Equation 21: $$C_i(t) = x_i(t) \qquad \text{for } t \le LT_i$$

For the number of carriers delivered in periods $t \geq LT_i$, a minimum lot size is defined. This minimum lot size is modelled as follows (with 1000 being a particular large number):

Equation 22: $y_i(t) \in \{0,1\}$

Equation 23: $$C_i(t) \geq C_i^{\min} - 1000 \cdot y_i(t)$$ $$C_i(t) \leq 1000 \cdot (1 - y_i(t))$$ for $t > LT_i$

The price of some carriers is time dependent. The price is calculated with the help of a parameter γ. This parameter is the average increase or decrease of the price per week.

Equation 24: $p_i(t) = \gamma_i \cdot p_i(t-1)$

The number of times that an available carrier can be used ($U_i^{\max}$) is the same as in the previous model. Also, the number of available and breaking carriers can be described by the same functions. This means that Equation 7, Equation 10, and Equation 11 are also used in this model.

A maximum production constraint is related to the machine capacity. This maximum production is the same for several periods and can be represented by $P_{year}^{\max}$.

Equation 25: $\sum_{i=1}^{N} P_i(t) \leq P_{2005}^{\max}$ for t = 1, 2, ..., 32

Equation 26: $\sum_{i=1}^{N} P_i(t) \leq P_{2006}^{\max}$ for t = 33, ..., 82

Equation 27: $\sum_{i=1}^{N} P_i(t) \leq P_{2007}^{\max}$ for t = 83, ..., 132

Equation 28: $\sum_{i=1}^{N} P_i(t) \leq P_{2008}^{\max}$ for t = 133, ..., 150

Finally, production cannot be negative, so:

Equation 29: $P_i(t) \geq 0$

Stochastic demand

Earlier, it was stated that the errors of the forecasts are normally distributed. It is possible to build a safety stock to cope with the uncertainty of demand. Under the assumption of normally distributed errors, this safety stock must be equal to a safety factor multiplied by the coefficient of variation of the forecast errors and the forecast itself.

Equation 30: $SS_i(t) = k \cdot cv_i \cdot F_i(t)$

The safety factor *k* is then determined by the stock-out probability:

Equation 31: $$p_{\varepsilon \geq}(k) = 0{,}01$$ $$k \approx 2{,}33$$

The forecasts are used to calculate the inventory in a period. The inventory level must be higher than the safety stock.

Equation 32: $I_i(t) = I_i(t-1) - F_i(t) + P_i(t)$

Equation 33: $I_i(t) \geq SS_i(t)$

Input variables
The inventory cost rates for end products and tools are found in the finance and accounting department. A holding cost percentage of end products of 8% per year is used, so h_1 = 0,0016 per week. For tools, the holding cost percentage is 7,6% per year, so h_2 = 0,00152 per week.

The maximum production in Equation 25 to Equation 28 is equal to the machine capacity. In the Bouwens model an aggregate capacity per year per product platform is used. Table 5-6 shows the aggregate capacities converted to capacities per week.

Year	Total SON production per week	Total CDM production per week
2005	387.000	234.800
2006	468.940	281.760
2007	574.500	338.100
2008	597.160	405.720

Table 5-6 Aggregate capacity numbers

The value of the products is recorded per product code number in the F&A department [20] and is averaged over the products in a group.

The delivery time of new carriers is found in SAP for CDM HT moulds and tiles. The initial prices and minimum lot sizes of CDM HT moulds and tiles are also in SAP [6]. For SON HT moulds, the initial price, minimum lot size and delivery time of carriers depend on the supplier's offer. The prices and minimum lot sizes in Appendix 14 are based on the current knowledge within the purchasing department.

From January 2000 to January 2004, the molybdenum price has increased with on average 23% per year. So, for SON HT moulds and CDM HT mould components, the time dependence parameter of the price is set to be γ = 1,004589. For tiles, the price increase is negligible, so γ = 1.

Input variable	**Recorded in**	**Department**
Aggregate machine capacity	Bouwens model	
Demand in previous 4 years	Sales database [9]	Marketing & Sales
Average value products	Delivery table [20]	Finance and Accounting
Minimum lot size	SAP [6]	Purchasing
Price carriers	SAP [6]	Purchasing
Delivery time carriers	SAP [6]	Purchasing
Lifetime data SON HT moulds	Belly and skewness file [13]	Factory Engineering
Average # products per carrier	SAP [16]	Production
Average throughput-time	Throughput-time table [17]	Production
Current number of carriers	Mould repair file [19]	Mould loading/unloading

Table 5-7 Input variables for the model

The initial value of the number of carriers available and the number of carriers in repair is taken from a special file, constructed to record these numbers. The initial value of the stock is the constant of variance times the safety factor times the average demand in the previous 12 months.

Specifications for SON HT moulds

For SON HT moulds, the functions for the repair shop, Equation 12, Equation 13, and Equation 14 are also used in this model. This means that the objective function given by Equation 19 changes to Equation 34.

Equation 34: $\min \sum_{i=1}^{N} \sum_{t=1}^{T} [h_1 \cdot v_i \cdot I_i(t) + p_i(t) \cdot [C_i(t) + h_2 \cdot (A_i(t) + R_i(t))]]$

Specifications for CDM HT moulds

CDM HT moulds consist of several parts. It is not possible to choose a different production volume for one component when this component is used together with another component. Therefore, the total production should be less than the production that is possible with the "bottleneck". This is the component that can carry the least products. In this model, the components are numbered j = 1 to 11.

To illustrate the idea above, consider the following example. Covers (8) are used for all product groups, which means that the production volume of 35W trays (1), 70W trays (2), and 150W trays (3) may not be more than the capacity of the covers.

The objective function then is:

Equation 35: $\min \sum_{i=1}^{N} \sum_{t=1}^{T} h_1 \cdot v_i \cdot I_i(t) + \sum_{j=1}^{J} \sum_{t=1}^{T} p_j(t) \cdot [C_j(t) + h_2 \cdot A_j(t)]$

Other functions change into:

Equation 36: $C_j(t) = x_t$ for $t \leq LT_j$

Equation 37: $y_j(t) \in \{0,1\}$

Equation 38: $C_j(t) \geq C_j^{\min} - 1000 \cdot y_j(t)$, $C_j(t) \leq 1000 \cdot (1 - y_j(t))$ for $t > LT_j$

Equation 39: $p_j(t) = \gamma_j \cdot p_j(t-1)$

Equation 40: $U_j^{\max} = \frac{7}{\lambda_j}$ for all t=1,...T

Equation 41: $A_j(t) = A_j(t-1) + C_j(t-1) - X_j(t-1)$

Equation 42: $X_j(t) = \frac{P_i(t)}{q_j \cdot a_j} + b_j \cdot A_j(t)$ for i dependent on j, for all j

Each carrier has its own production constraint, because the production for a certain product type must be less than the maximum production for all carriers needed for this type. These constraints are:

Equation 43: $P_2(t) \leq q_j \cdot f_j \cdot A_j(t) \cdot U_j^{\max}$ for j = 1

Equation 44: $P_1(t) + P_3(t) \leq q_j \cdot f_j \cdot A_j(t) \cdot U_j^{\max}$ for j = 2

Equation 45: $P_4(t) \leq q_j \cdot f_j \cdot A_j(t) \cdot U_j^{\max}$ for j = 3, 6, 7

Equation 46: $P_1(t)+P_2(t)+P_3(t) \le q_j \cdot f_j \cdot A_j(t) \cdot U_j^{\max}$ for j = 4, 5

Equation 47: $P_1(t)+P_2(t)+P_3(t)+P_4(t) \le q_j \cdot f_j \cdot A_j(t) \cdot U_j^{\max}$ for j = 8, 9, 10, 11

Specifications for CDM tiles
As the number of loops in a week is a fixed number, the decision on a certain production volume per week automatically generates a production volume per loop. Again, the number of loops per week is *B* and τ_i is the number of tiles per loop for each tile type. Equation 20 then changes to Equation 48 and Equation 49 is a constraint to decide on the number of tiles. In this equation the denominator is rounded up to get a number that is a plural of the loop size.

Equation 48: $P_i(t) = B \cdot \tau_i(t) \cdot q_i$

Equation 49: $\tau_i(t) \le \dfrac{A_i(t)}{\left\lceil B \cdot \dfrac{\lambda_i}{7} \right\rceil}$

For one kind of CDM end product, two sorts of tiles are used; this is also shown in Appendix 2, Figure A 4-2. So, the production volume on a tile may not be more than the capacity of another tile that is used for the same product. For this reason, a set of indices is added to the model. The carrier groups are represented by *j* = 1, ..., J and the product groups are *i* = 1, ..., N. This means that the model changes are the same as in the specification for CDM HT mould components.

The production constraints for CDM tiles are:

Equation 50: $P_1(t) \le q_j \cdot f_j \cdot A_j(t) \cdot U_j^{\max}$ for j = dotted tile

Equation 51: $P_2(t)+P_3(t)+P_4(t) \le q_j \cdot f_j \cdot A_j(t) \cdot U_j^{\max}$ for j = flat tile

Equation 52: $P_2(t) \le q_j \cdot f_j \cdot A_j(t) \cdot U_j^{\max}$ for j = holed tile, 361 holes

Equation 53: $P_1(t)+P_3(t) \le q_j \cdot f_j \cdot A_j(t) \cdot U_j^{\max}$ for j = holed tile, 225 holes

Equation 54: $P_4(t) \le q_j \cdot f_j \cdot A_j(t) \cdot U_j^{\max}$ for j = holed tile, 144 holes

Results
For the current situation, the model is evaluated by using the values as defined in Appendix 14 and the demand in the previous four years. The output from this model is in Appendix 14 as well.

The model builds up stock, but at the end of all periods, this stock is being brought down again because the horizon is not infinite. If it had been infinite, it would probably buy new carriers because demand is increasing, also after 150 weeks. However, this output does not make any difference for the decision to buy carriers, because stock is being built up after the next evaluation moment of the model, which will be around period 37.

For SON HT moulds, the model was evaluated over a total period of 150 weeks. The model advised not to buy any carriers in period 27 for 1000W moulds. Increases in production were dealt with by keeping inventory. It can be seen that inventories are built up for the carriers that are currently on the shorter side.

For CDM HT moulds, the model was only evaluated over a total period of 100 periods, because otherwise the model became too large. In period 26, 49 covers arrive and 100 head sheets arrive in period 27. Here, carrier capacity is on the short side for carriers that are necessary for all products and therefore inventory is built up for the products with the lowest value. For these products, the inventory costs are lowest.

For CDM tiles, the model was also evaluated over a total period of 100 weeks. For this model, it is likely that the purchaser will advise to combine orders. For example, flat tiles are planned to arrive in period 24 and 28 and it is probably cheaper to place those orders together.

Sensitivity analysis
It was investigated how robust the models with joint optimization for carriers and end inventories are. For this purpose, the forecasts were increased by a certain percentage and the output of the model with increased forecasts was compared to the output of the original model. It was evaluated for which percentage the model was feasible and for which percentage the carrier purchases differed from the original model.

	Forecast increase possible	Forecast increase possible without changes in carrier purchases
SON HT moulds	6%	6%
CDM HT mould components	4%	4%
Tiles	4%	0%

Table 5-8 Forecasts increases possible for the joint optimisation models

For SON HT moulds, the carrier purchases do not change for forecast increases to 6%. If the forecast is increased with percentages higher than 6%, problems occur due to the delivery time of the carriers. However, the number of carriers to buy, the main decision variable, is the same for forecast increases up to 6%.

For CDM HT mould components, the current capacity of carriers is shorter than it is for SON HT moulds. The forecasts can be increased with 4%; for increases higher than 4%, the model is infeasible. The number of carriers to buy remains the same for forecast increases up to 4%.

For tiles, the forecasts can also be increased with 4% for the model to be feasible. However, the purchases for carriers do change with a forecast increase of 4%. Tiles are now planned to arrive in period 15, whereas earlier they were planned to arrive in period 24 for the first time.

5.2.4. Joint optimisation of operators and SON HT moulds

Currently, SON HT moulds are processed in the oven seven days a week, 24 hours a day. Nevertheless, the loading and unloading operators only work in dayshift, 5 days a week, 8 hours a day. This means that sometimes a large buffer of loaded moulds is necessary before and after the oven. It is possible to have operators working in 3 or 5 shifts. This would reduce the throughput-time of the moulds and thus the number of moulds needed, since the work in process in the buffer before and after the oven would be smaller.

Description of the model

So, having operators working in 3 or 5 shifts could reduce costs, because fewer carriers are needed. However, operators in 3 or 5 shifts are more expensive. It is tried to find out if it would be cheaper to have loading and unloading operators work in 3 or 5 shifts. The costs of the three possibilities are separately evaluated and compared to each other.

This means that the objective function is the same as in the previous section, except that the costs for having operators are also added to the total costs. The decision variables and other variables are also the same as in the previous section. Three parameters represent the costs of having operators and are defined in Appendix 10.

Equations

The model in section 5.2.3 is now evaluated for operators working in dayshift, 3 shifts, and 5 shifts, with the operator costs added to the model and with lower throughput-times for the situations with 3 and 5 shifts.

The costs per month for having one operator working in dayshift are represented by k_1. The costs per month for having one operator working in 3 respectively 5 shifts are represented by k_3 and k_5. Currently, there are 10 operators working in the loading and unloading department. It is assumed that this number remains the same. This assumption is necessary to make a good comparison between the three alternatives.

Since the model is evaluated over a total period of 150 weeks (3 years), the costs for operators are multiplied by 36 months. The operator costs are added to the objective function in section 5.2.3. Equation 55 shows the new objective function for having operators in dayshift, and Equation 56 and Equation 57 show the objective functions for having operators in respectively 3 and 5 shifts. The remaining of the model in section 5.2.3 is the same. Only the throughput-times are changed for the situations with 3 and 5 shifts.

Equation 55: $\min \sum_{i-1}^{N} \sum_{t=1}^{T} \left[h_1 \cdot v_i \cdot I_i(t) + p_i(t) \cdot \left[C_i(t) + h_2 \cdot \left(A_i(t) + R_i(t) \right) \right] \right] + 36 \cdot 10 \cdot k_1$

Equation 56: $\min \sum_{i-1}^{N} \sum_{t=1}^{T} \left[h_1 \cdot v_i \cdot I_i(t) + p_i(t) \cdot \left[C_i(t) + h_2 \cdot \left(A_i(t) + R_i(t) \right) \right] \right] + 36 \cdot 10 \cdot k_3$

Equation 57: $\min \sum_{i-1}^{N} \sum_{t=1}^{T} \left[h_1 \cdot v_i \cdot I_i(t) + p_i(t) \cdot \left[C_i(t) + h_2 \cdot \left(A_i(t) + R_i(t) \right) \right] \right] + 36 \cdot 10 \cdot k_5$

Input variables

When there are more shifts, the average throughput-time will be lower. This means that the average of the maximum number of usages is higher. A simulation was carried out to investigate the effect of working in 3 or 5 shifts. This simulation is described in Appendix 15. The results of the simulation are used to find an approximation of the throughput-times in the three situations.

The F&A department provided the costs for operators in the three situations. A loading operator is classified into a certain salary scale. Because operators in other departments are already working in 3 or 5 shifts, the costs for loading operators in this scale are also known.

Results

Because the operator costs are not influenced by the decision variables, the output of the model in dayshift remains the same. This means that no carriers are bought, but that high inventories are built up to deal with deficits for carriers at the end of the three years. For the models with operators working in 3 or 5 shifts, no carriers are bought either, but fewer inventories are built up now.

Table 5-9 shows that the total costs are higher when working with operators in three or five shifts. The savings on the inventory costs are not enough to deal with the higher operator costs.

	Inventory costs	Carrier costs	Operator costs	Total costs
Operators in dayshift	€ 40.668	€ 638.390	€ 857.880	€ 1.536.938
Operators in three shifts	€ 36.217	€ 638.430	€ 1.046.880	€ 1.721.526
Operators in five shifts	€ 36.217	€ 638.430	€ 1.086.120	€ 1.760.766

Table 5-9 Costs for the three possible situations of operators

However, it is expected that for higher demand, carrier purchases will be necessary for the situation with operators working in dayshift. Therefore, the model is also evaluated with the same forecasts, but 30% higher in the second year and third year. As can be seen in Table 5-10, the carrier costs are indeed higher for the situation with operators working in dayshift.

	Inventory costs	Carrier costs	Operator costs	Total costs
Operators in dayshift	€ 133.352	€ 821.867	€ 857.880	€ 1.813.099
Operators in three shifts	€ 126.889	€ 629.336	€ 1.046.880	€ 1.803.105
Operators in five shifts	€ 48.987	€ 630.551	€ 1.086.120	€ 1.765.658

Table 5-10 Costs with demand 30% higher in the second and third year

5.2.5. Comparison of models

The models that are constructed for the strategic carriers are compared to each other to come to a good decision on the model to use.

The costs of the joint optimisation of end products inventories and carriers (5.2.3) are equal to the outcome of the objective function. The costs of the simple model (5.2.2) are the sum of the costs for buying new carriers and holding carriers.

Equation 58: Costs in simple model $= \sum_{i=1}^{N}\sum_{t=1}^{T} p_i(t)\cdot\left[C_i(t)+h_2\cdot A_i(t)\right]$

These costs are summed over a total period of 150 weeks for SON HT moulds, and 100 weeks for CDM HT mould components and tiles. This is in order to get a good comparison with the costs of the joint optimisation model that were also evaluated over these periods.

	Simple model (5.2.2)	Joint optimisation inventories and carriers (5.2.3)
Total costs for tiles	€ 795.708	€ 166.455
Total costs for CDM HT mould components	€ 491.090	€ 246.395
Total costs for SON HT moulds	€ 1.991.952	€ 678.701

Table 5-11 The total costs for strategic carriers for two models

Table 5-11 shows that the costs for the simple model are much higher in all cases. For tiles the costs can be reduced with 79% by using the joint optimisation model. For CDM HT mould components, the reduction is 50% and for SON HT moulds it is

66%. It was to be expected that the reduction would be the largest for tiles, because the highest expenses are made for tiles in the simple model. Thus, the most money can be saved in the joint optimisation model.

On the basis of the large savings with the joint optimisation model, it is recommended to use this model to calculate how many new carriers must be ordered. This model should be evaluated four times a year, so that a rolling horizon is introduced and so that the effects of a finite horizon are minimized.

On the basis of the costs for operators, it is advised not to change to a situation with 3 or 5 shifts yet. Only if demand grows with more than 30%, it will be profitable to have operators working in 3 or 5 shifts, because fewer inventories are to be kept then and fewer carriers are to be purchased.

5.2.6. Model for nozzles

Nozzles are compiled of three components, namely a die, an extruding punch and a punch holder. Nozzle components are kept on stock, even as compiled nozzles. When a complete nozzle breaks down or does not function optimally, it is replaced by a compiled nozzle from stock. When during the weekly check the component's dimensions are not within specifications, this component is replaced by a component from stock.

Description of the model

The relevant costs for nozzles are the costs for keeping nozzles and nozzle components on stock and the costs for buying new components. The components are compiled at Philips. The stock value of a compiled nozzle is from now on assumed to be equal to the value of the components that compile the nozzle.

The price of a component depends on the order quantity, because components are bought with quantity discounts. The price of a component is represented by $P(Q)$, with Q being the order quantity.

It is assumed that demand for nozzle components is Poisson distributed. This assumption is justified because the hypothesis that demand was Poisson distributed could not be rejected with 90% certainty, for all nozzle components over period of 2 years. Furthermore, the replacements of a component are independent of each other and demand is stationary. The parameter μ represents the Poisson distribution and is the average demand per week for a component.

It is recommended to use an (s,Q) policy. The optimal order quantity (Q) and the order point (s) are determined for each component. When the stock for a component is at its order point, new components are ordered according to the optimal order quantity. The main reason to choose an (s,Q) policy is because it is easy to understand. Order points and fixed order quantities are currently used as well. Furthermore, the primary disadvantage of the (s,Q) policy is that it may not be able to effectively cope with large transactions [13] and this does not apply here.

A decision is made upon the order point s and the order quantity Q. First, the best order quantity Q is calculated, and then the order point s that leads to a stock-out frequency lower than 0,1% is found. This frequency is the objective of the model. The notation of the decision variables and other variables is given below. The definitions of the parameters for the nozzle model are in Appendix 10.

Decision variables	
Q	Order quantity in number of components
s	Order point at which a reorder for components is made
Variables	
$C(Q)$	Total costs for buying order quantity Q
$O(s,Q)$	Out-of-stock frequency, given a certain order quantity Q and order point *s*
IN	Inventory of components

Calculation of order quantity

First, the optimal order quantity Q is determined by balancing the quantity discount against the holding costs. Because different prices are specified for 1 component, 2 components and more than 2 components, the alternatives are to order 1, 2 or 3 components. For each alternative the expected holding cost is added to the price (*p*) of the component, both dependent of the quantity ordered. The holding cost percentage h_2 used for carriers is also used for nozzle components. The total costs are compared in a table and the cheapest alternative is chosen.

Equation 59: $c(Q) = \frac{Q}{\mu} \cdot h_2 \cdot p(Q) + p(Q)$

Calculation of order point

Next, the order point s can be determined by choosing a maximum stock-out frequency, *O*. Since nozzles are highly important in production, the service level should be 99,9%. This means that *O* must be smaller than 0,001.

For various order points s the stock-out frequency *O* is calculated until $O < 0{,}001$ is reached. The stock-out frequency can be calculated by the chance that the inventory (*IN*) is less than or equal to zero. [21] This probability is described by:
Equation 60: $O(s,Q) = \Pr\{IN \leq 0\}$

If the order size would be fixed to Q=1, the probability of an out-of-stock situation would be equal to the probability that demand D during the delivery time *L* is equal to or larger than the order point plus the order quantity, i.e. s + 1. This probability can be calculated by using the probability mass function (pmf) of demand, *g* and its complementary cumulative distribution function (ccdf) G^0.

The probability mass function is the probability that *x* is equal to a certain value [14] and is for the Poisson distribution calculated by [21]:

Equation 61: $g(x) = e^{-\mu L} \frac{\mu L^x}{x!}$

The cumulative distribution function is the probability that *x* is smaller than a certain value and is calculated by [21]:

Equation 62: $G^0(K) = 1 - \sum_{x \leq K} e^{-\mu L} \frac{\mu L^x}{x!}$

This leads to Equation 63 for the stock-out frequency, if the order size is fixed to Q=1.

Equation 63: $O(s,1) = \Pr\{D(L) \geq s+1\} = G^0(s) = 1 - \sum_{j<s} g(j) = 1 - \sum_{j<s} e^{-\mu L} \frac{\mu L^j}{j!}$

However, if the order quantity Q is variable, the stock-out frequency can be represented by the summation of stock-out frequencies of policies with a lower Q times the probability that the inventory position is equal to the order point s. The probability that the inventory position is equal to the order point s, is 1/Q. To find the stock-out frequencies of policies with a lower Q, the first-order loss function, G^1 is used. This function is the probability that the cumulative distribution G^0 is smaller than a certain value:

Equation 64: $G^1(x) = -(x - \mu L)G^0(x) + \mu L g(x)$

Equation 65: $O(s,Q) = \Pr\{IN \leq 0\} = \left(\frac{1}{Q}\right) \cdot \sum_{j=s+1}^{s+q} \overline{A}(j) = \left(\frac{1}{Q}\right) \cdot \left[G^1(s) - G^1(s+Q)\right]$

Input variables
It is recommended to use the maximum delivery time for nozzle components, because that assures that the chance for a stock-out is lower in reality. Currently, the maximum delivery time is 10 weeks.

The demand can be found in a file that is constructed to look up the demand per nozzle component. This file is described in section 5.3.

Appendix 16 gives two examples of the calculation of the order quantity and the base stock level.

Procedure
Currently, compiled nozzles are kept on stock, just as components of nozzles. During the weekly check the mechanic takes replacement components from stock. The compiled nozzle is used if a nozzle breaks down during the night shift (when no mechanic is present) and production needs a spare nozzle. If the stock for a certain component is zero and there still is a nozzle with the needed component in it, the mechanic may also use the nozzle.

The most important reason to have individual components and compiled nozzles on stock is to guarantee that the production department always has fast access to a spare nozzle. A disadvantage of this policy is that the total stock is high and that this leads to higher costs.

The model only specifies order points for components. It is recommended to evaluate the order points for each component and to put at least one item in the stock for individual components. One component on stock is the minimum because in general the mechanic must be able to take a replacement component from stock right away. If the order point is higher than one, the remaining components can be assembled into nozzles. The first component is used for the most used nozzle, and so further, until no more than one component is left.

5.3. Recording information

To use the models discussed above, it is necessary to have information about all input values. In the existing situation, most variables were recorded but some information was not available.

Number of carriers
The number of available carriers was unknown. Therefore, all strategic carriers were counted and the results were recorded. It is recommended that for each strategic

carrier sort one or two employees be assigned to record the information about the number of available carriers. There are three tasks that have to be accomplished, namely recording carriers broken down, recording new carriers taken into production, and a yearly physical count. This physical count is in order to assure the correctness of the information records.

For SON HT moulds, there is one additional task, namely recording the number of carriers that are repaired and return into production. This task is also carried out by a mould loading operator.

	Recording carriers broken down	Recording carriers taken into production	Yearly physical count
Tiles	Foreman CDM department	Foreman CDM department	Foreman CDM department
CDM HT mould components	Mould loading operator	Mould loading operator	Controller incoming materials
SON HT moulds	Mould loading operator	Controller incoming materials	Controller incoming materials

Table 5-12 Tasks and responsibilities for recording the number of carriers

The possibility of RFID (Radio Frequency Identification) to record the number of carriers was examined, but RFID-tags are currently only resistant for temperatures to 900 degrees. The temperature in the high-temperature ovens is 2000 degrees so that it is not possible to use the tags for the tiles and molybdenum carriers.

Breaking rates
There was also not much information about the breaking rates of the carriers. Detailed information was only available for 150W and 400W SON moulds. To make better estimations of the percentage of carriers breaking down per week, the files with the carrier records can be used. In these files, it is recorded how many carriers are thrown away because they broke down. The average percentage per week can be used as an input variable for the percentage of carriers breaking down per week.

Nozzles
For nozzles, the demand per nozzle component was unknown. It was only recorded from which nozzle a component was replaced, but the code number of the component was not registered. Therefore, a file was constructed in which the repairer can record the components that he replaces. For every component it can now be seen how many items were replaced in the previous periods.

5.4. New equipment projects

To find precautions against the problem that new equipment projects lead to problems with carrier deficits, the execution of the projects is investigated. After a general description of the projects, problem areas are indicated and solutions are recommended.

5.4.1. Description of new equipment projects

A flowchart description of the procedure of new equipment projects in Dutch is in Appendix 17. [22] In short, the course of the projects is as follows:
Step 1. Setting specifications for new equipment (phase 3 in Appendix 17)
Step 2. Purchasing or design and build the new equipment (phase 5 in Appendix 17)
Step 3. Test the equipment on the production floor (phase 7 in Appendix 17)
Step 4. Release the new equipment (phase 9 in Appendix 17)

5.4.2. Causes for helping tool problems

New equipment project teams are concerned with setting the technical specifications, ordering and testing the equipment. The project members will not consider the consequences for carriers or helping tools, neither for planning or number of operators needed. As a consequence, in the third phase it is discovered that not enough resources are available to take the machine into production. So, there is a mismatch between the purchase of equipment and the purchase of the corresponding resources.

The reason for this mismatch is in the first place that the official procedures for new equipment projects do not contain any trigger to control the availability of helping tools. Moreover, the project members are all engineers who are technical specialists and who are unable to oversee the other issues of the project.

5.4.3. Precautions for new equipment projects

To reduce the problems with helping tools as a consequence of new equipment projects, two recommendations are made.

First, helping tools consequences must be included in the official procedures of the project. The following changes are recommended.

1. Include a study to the helping tools needed for the new machine in the preparatory study during step 1. This means that the checklist for passing milestone 1 (MMP-1in Appendix 17) also contains an item 'specification of needed resources'.
2. Purchase the helping tools specified in the first step during step 2, possibly only in small amounts. The checklist for passing milestone 2 (MMP-2 in Appendix 17) should then contain an item 'needed resources available'.
3. If necessary, purchase more helping tools to run production smoothly on the new equipment during step 3 and 4. The checklist for passing milestone 4 (MMP-4 in Appendix 17) then contains the item 'enough resources available'.
4. Update the order quantities and order points of the specified resources in SAP to have a better control in future as well. This should be done during step 4 and it means that the checklist for milestone 4 (MMP-4 in Appendix 17) should also be extended with an item 'update SAP records for specified resources'.

Second, to ascertain that the project team is able to carry out the procedure as described above, it is recommended to improve the cooperation between the project team and the employees that have to take the machine into production.

5.5. New product introductions

Regularly, new products are developed for production at Philips Uden. The introduction of these products is initiated on the basis of customer demand. One customer asks for a new product with specific characteristics.

New product introductions can lead to problems for carrier capacities. The new products may need different carriers or, more often, the need for an existing carrier increases because demand in a product group grows after the development of the product.

For this reason, it is investigated how new product introduction projects are carried out and how the need for carriers could be foreseen at an early stage in the project. First, the current method for release projects is explained and then the possibilities for precautions against the consequences for carrier deficits are discussed.

5.5.1. Description of new product introduction projects

Officially, new production introduction projects are conducted as described in Appendix 18. [23] The head of the product development department and product developers were interviewed to learn about the different types of release projects. Now, the four types of release projects are described. Later, the general structure of all projects is described.

Types of projects

First, there are the projects in which an existing product type is minimally changed. For this kind of projects the ambition is to have a throughput-time of less than one week, because only the product documentation has to be made and the product must get a code number.

Second, within-range line extension projects develop products that have physical dimensions within the current range of product dimensions. These products must be tested before release but most of the tooling is already available; the throughput-time of such projects is between 8 and 16 weeks.

Third, in the out-of-range line extension projects, products are developed that are based on the current products but that have dimensions smaller or larger than the current product dimensions. This means that new tooling (with long delivery times) may have to be ordered, so that the throughput-time of these projects is typically 4 to 8 months. Since the products developed in these projects are out of the current range, these products may also need another kind of carriers.

Finally, new-platform projects lead to products that are completely different from the current products. Most of the time, other carriers will be needed but also another production method. For this reason, these projects are considered as new equipment projects, which are handled in the previous section.

The first three projects can also be classified according to another set of categories, namely projects that lead to new sales on top of the existing demand and projects that lead to sales substituting existing demand. The first category has serious consequences for the need for carriers, because the demand for a certain carrier group grows. The second category only has consequences in the case that a new kind of carrier is needed.

Structure of the projects

Each project more or less has the same structure. The project starts with filling in a project start form that contains information about the product to be developed and the expected sales for the product. This form is the start for designing the product and, if necessary, the production process.

The product developers use a computer application during the first steps of the new product introduction. This application is based on general design rules and returns the tooling and materials needed, after the developer has entered the product specifications. For example, the inner tube width is entered and the application returns the punch needed with a diameter that is 2mm less than this inner tube width. For projects of kind 2 and 3, if necessary, new tooling is then ordered on the basis of this output. During this first stage, also some samples are produced at the development department.

When the tooling has arrived, small batches are produced in the production department to test the performance of the tools. After having done enough tests, the product is released and is produced regularly.

5.5.2. Precautions for new product introductions

The developers currently use a computer application that returns the tooling and materials needed for a specific product. It is recommended to extend this application so that it also returns the sort of carriers needed on the basis of the product's dimensions.

At the beginning of the project, the developers also make a prognosis for the expected sales for the new product. This prognosis is based on the information that the customer who asked for the new product, has provided. The information on the kind of carrier needed can be combined with this prognosis in the tool that was described in section 5.2.3. The developer goes to the controller of the carriers, who enters the prognosis and kind of carriers into the tool. This tool calculates how many carriers are needed after the introduction of the product.

Still, if the tool calculates that new carriers must be ordered and if these carriers are ordered right away, they may arrive too late in many cases. Therefore, it is important that the controller of the tool is conscious of possible new product introduction projects. As described in section 5.2.3, the tool for strategic carriers is evaluated four times a year during a planners meeting. It is recommended that the group leader product development is present at this meeting as well.

It is also possible that the carriers that are currently in use cannot be used for the new product. Then, it is more difficult to order the right carrier quantity because the capacity of the new carrier sort is unknown. Partly, good project management can prevent this. It is important that the project team is capable to estimate the expected sales for a certain product and the consequences for the carrier need. The tool developed in this study is not appropriate for that purpose.

6. I-phase: Implementation

This chapter describes how the solutions recommended in the previous chapter are or are to be implemented. Part of the plans described is actually executed during the project; the other part is a description of how the solutions must be implemented in future.

6.1. Restricted access

The group leaders of production and R&O were asked which persons need access to the warehouse. The list based on their judgement was discussed with the production manager and a final list was constructed with 9 employees on it.

The facility manager was asked to order a system that would control the access to the technical warehouse. This system only permits persons that carry an authorized badge to enter the warehouse. Since badges are already in use by all employees, only a badge reader and a lock linked to this badge reader have to be installed. The costs for the installation and the badge reader and lock are € 5000.

Currently, a mechanic, whose main task is not the technical warehouse but the repair and maintenance of equipment, manages the warehouse. When access is restricted, employees without access will need the help of the warehouse manager when they need an item out of the technical warehouse. This means that the job of warehouse manager will become too large for the current manager. It is therefore recommended to hire a new warehouse manager and to start the implementation of the restricted access when this manager is installed.

To implement the new procedures, the employees that currently use the warehouse are informed on the new system and on the reasons for changing the procedure. The employees that will have access in the new situation get an instruction of how to use the technical warehouse. It was also explained that the performance of the inventory accuracy would be recorded on the basis of the ABC-cycle counts.

6.2. Changing units of measure

The units of measure in SAP are all changed so that the chance of recording the wrong quantity of a shipment decreases. The purchasing assistant was asked to make a list off all items in the technical warehouse that perhaps had the wrong unit of measure in SAP. Then the warehouse manager checked the items on the list and reported for which items the packaging quantity actually was the unit of measure. The recorded inventory was then changed to represent the real stock in pieces.

To guarantee the use of adequate units of measure in future, the warehouse manager was asked to keep control of the units of measure. He is able to control the inventory records.

6.3. ABC cycle counting

Support for the ABC-cycle counting was already created within the project team by the group interviews and ranking sessions on the solutions for the warehouse.

First, the warehouse manager and another mechanic gave each item an indicator, A, B, or C. The indicator was given on the basis of the following definitions:

A. This item is critical to a machine that produces at least half of the products in this step and the item has a long delivery time from the supplier (more than one week).
B. This item is critical to a machine that produces less than half but more than 10% of the products in this step or the item has a short delivery time from the supplier (less than one week) and is critical to a machine that produces at least half of the products in this step.
C. The other items.

The indicator A was given to 490 items; 617 items got a B, and 947 a C. The project team preferred to count the A-items 4 times a year, the B-items twice a year and the C-items once a year. It is recommended to use these frequencies as a starting point. If it turns out that inventory accuracy is not accurate enough or more accurate than necessary, it is possible to change the frequencies.

It is recommended to begin the ABC-cycle count procedure on the 8^{th} of August, after the company holidays. Before the holidays there is not enough time left to introduce the procedure and to get used to working with it.

Every week, the warehouse manager will print a list that is generated by the SAP system. On the list are the items that have to be counted and the stock that is recorded in the SAP system. During the week, the manager will check the accuracy of the records. If the inventory for an item is not equal to the inventory on the list, the manager corrects the stock information in the SAP system.

The warehouse manager will also record for how many items the information was accurate and for how many it was not. He calculates the inventory accuracy percentage and publishes this percentage so that all employees with access to the warehouse are conscious of it.

When counting A-, B-, and C-items respectively 4, 2, and 1 times a year, in total 4139 counts have to be made every year. In an average year, there are 50 production weeks, so that each week (4319 / 50 =) 83 counts have to be made.

It was evaluated how much time these counts would cost by taking a random selection of all items. The selection contained in total 87 items, of which 41 A-items, 26 B-items and 20 C-items, so it was a good representation of a count in a certain week. Then, the items on the selection list were randomly divided into three groups of 22 items and one group of 21 items. The average time for checking the inventory accuracy of one group was 14,5 minutes, with a standard deviation of only 1,9 minutes. The total time for 83 counts is thus expected to be (83 / 21,75 × 14,5 =) 55 minutes per week.

6.4. Tool

6.4.1. Tool for leverage and bottleneck carriers

Leverage carriers (metal baskets) are not kept on stock until now and this is not recommended either. Once a year, the model in section 5.2.1 is used to evaluate if new carriers must be purchased during the planners meeting. If in between the group leader production thinks that more metal baskets are necessary, he asks the controller to evaluate the model already.

Bottleneck carriers are kept on stock and it is recommended to maintain this situation. An official proposal was made to change the order points into the order points defined in Appendix 11. Furthermore, once a year during the planners meeting, the model is evaluated with new input variables, for demand or the quantity carried. Afterwards, the order points may have to be changed as well.

6.4.2. Tool for strategic carriers

For strategic carriers, it is recommended to use the model with a joint optimisation of inventories and carriers. It is recommended to link all input variables in Table 5-7 in a database that can calculate the number of carriers needed and the production volumes necessary. The project leader of the project to extend the capacity of the CDM department is asked to do this. He has experience with databases and understands the working of the model. It is expected that the construction of the database can be finished within a month after the end of the project and that from then on, the model will be used.

Preparing the model evaluation

Every 3 months, during the planners meeting, the output of the models is discussed and decisions to buy new carriers are made. The production manager prepares these reviews by updating the inputs and evaluating the new results. If the results differ from what was expected, the production manager can also change the input variables. For example, it is possible to do a sensitivity analysis by increasing or decreasing the demand forecasts.

Input for the models is among others the number of carriers that is available for production plus the number of carriers in the warehouse. Therefore, it is important that the controller of the model discusses this input with the employees responsible for the carrier records.

Results of the models

During the planners meeting, the results are discussed and a decision to buy new carriers is made. This decision is not only supported by the output of the model, but also by contributions from the sales department and the development department. The sales department is already represented at the planners meeting, but the product development department is not. Thus, it is recommended to ask the developer to be part of the planners meeting. After the planners meeting, the advice of the purchaser is asked to help decide on the order quantity or the moment of purchase.

The other decision variable of the model, the production volumes, must also be discussed during the planners review. The output of the model is production volumes per week per product group. The product mix of product types in a product group is the same as the current product mix.

Currently, some carriers have no spare stock in the warehouse and others have. For the carriers that have a spare stock in the warehouse, order points and order quantities are used to control this stock. For the carriers that have a spare stock, it is recommended not to use order points anymore but to order new quantities if the model says so.

6.4.3. Tool for nozzles

For nozzles, it is first necessary to calculate the order points and order quantities for each component. Input for these calculations is the file with replacements per component and the method is described in section 5.2.6. Thereafter, it can be evaluated which compiled nozzles must be kept on stock. Then, the order point and order quantities in SAP are changed according to the calculated numbers. These are the initial actions that must be executed to implement the new procedure for nozzles.

To keep working according to the new method, the order point and order quantities should be recalculated once a year. This is the responsibility of the purchaser. He can use the method in section 5.2.6 to do this.

6.5. Recording information

To get a valuable output from the tools, it is critical to have the right input. Therefore, employees are assigned to keep records of this input.

The actual number of carriers available is the most important input variable. Employees were assigned to keep records of the number of carriers and files were constructed for this purpose. In these files the number of newly arrived carriers are recorded, as well as the updates of the yearly count of the carriers. For SON HT moulds, this file is the same as the file in which the number of carriers in repair is recorded.

The file constructed to keep track of the replaced nozzle components was explained to the mechanics responsible for replacing the components. They were also made responsible for keeping the file up-to-date as to nozzles in the list. The operators were conscious of the benefits of having knowledge of the replacements per component, so that they were willing to implement the use of the new file. To assure that this file is also used when new employees are responsible for the nozzles, the new procedure was documented at the Machine and Product Documentation department (MPDL).

6.6. Changes for projects

6.6.1. Evaluating carrier need at project start

The product developers currently use a computer application that returns the tooling and materials needed for a new product. To be able to evaluate the consequences of a new product introduction for the number of carriers needed, it was recommended to add a field to this application that returns the kind of carrier needed. One of the product developers was asked to list for all strategic carriers what the minimum and maximum dimensions of the carried products are. The product developer also changed the designer program, so that it returned the kind of carriers needed.

6.6.2. Triggers for helping tools in procedures

Simultaneously to this project, a project named MCRS (Management Control and Reporting System) was executed to improve the performance of the development department within Philips Uden. The MCRS project redefines the procedures for projects and the requirements for passing milestones. This involves the procedures for both new product introductions and new equipment projects.

It was recommended to the MCRS project team to specify the following requirements for passing milestones:

- A specification of the needed helping tools at the beginning of the project

- A check for the availability of helping tools before the project is released into production
- An adjustment of the data in SAP for helping tools before the project is released into production

These requirements were indeed included into the new procedures. These procedures will be made officially in September 2005.

The MCRS project team was already working on a method to assure a smooth transfer from development to production. This method specifies that the client of the project (mostly the production manager) is involved during the development and that specifications of the product are communicated with the client.

7. C-phase: Conclusions and recommendations

This chapter describes what the results of this project will be and what can be done to improve the control of resources even more.

7.1. Metric

In the E-phase, a target was set for the outcome of the project. The graph in Figure 7-1 shows the metric values and the target for tiles and CDM HT mould components. The figure shows that since the beginning of the project (October 2004) the metric values did not significantly improve or decline.

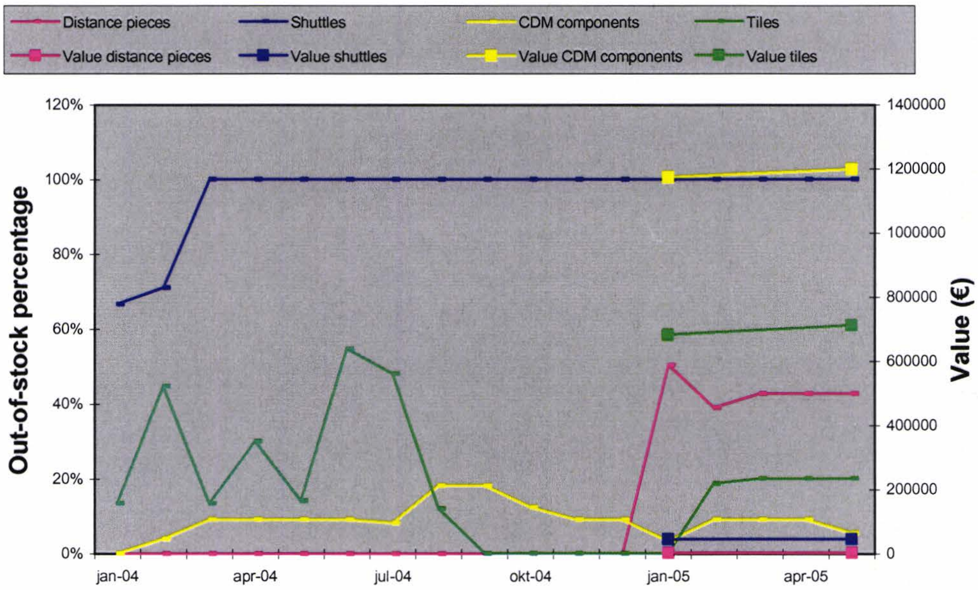

Figure 7-1 Value of the metrics in 2004 and 2005

The current out-of-stock percentage for the carriers is the percentage of carriers that is not available in the technical warehouse. It is evaluated how many carrier will be ordered in the next year on the basis of the model in section 5.2.1 and 5.2.3 and what the consequences of these orders are.

	Current value	Current out-of-stock percentage	Increase in value	Resulting out-of-stock percentage	Increase in value in terms of percentage
Shuttles	€ 45.120	100%	€ 4.640	0%	10%
Distance pieces	€ 2.882	43%	€ 119	0%	4%
Tiles	€ 711.152	20%	€ 42.821	0%	6%
CDM HT mould components	€ 1.198.916	5%	€ 15.296	0%	1%

Table 7-1 Expected changes in metric values after completion of the project

The controller of the model should keep track of the value for the metrics and the values of the metrics must be discussed during the planners meeting. This guarantees that the project is evaluated and that options for improvement are pursued, even after the project.

7.2. Performance indicator for inventory accuracy

To evaluate the solutions recommended for inventory accuracy, the accuracy indicator is a good measure. This indicator is simple the percentage of items for which the inventory record is accurate. Every week, this indicator can be updated, after the ABC cycle count for that week.

7.3. Recommendations

In section 5.5 precautions for new product introductions were recommended. However, these precautions may not be sufficient if the expected sales for a new product deviate from the real sales or if the current carriers cannot be used for the new product. Therefore, it is recommended to carry out a study to improve the forecasting of the expected sales for a new product. It is also recommended to improve the calculation of the need for new carriers by investigating the capacity and the breaking rate of these carriers. These topics are not included in this project.

Currently, the prognosis for the expected sales is based on information from the customer asking for the information. However, there are more sophisticated methods to develop forecasts before the product is introduced. It is possible to estimate the shape and the height of the demand curve by using the demand curves of similar products that are already introduced. Market research studies can further support the forecasts. [24] This would mean that the marketing and sales department is more involved in determining the prognosis for the expected sales of a new product.

To have better insight in the number of carriers that must be purchased when a new carrier sort is necessary, it is important to make good estimations of the capacity of the new carrier sort and the breaking rate. Perhaps, a failure mode analysis of the carrier sort could help to make such an analysis.

7.4. Conclusions

It is expected that the out-of-stock percentage of carriers in the technical warehouse can drop to zero, but this target cannot be reached without an increase of the total value of those carriers. Currently, the reported out-of-stock percentage may not be right, because of the low inventory accuracy. If the inventory accuracy is improved, the out-of-stock percentage becomes a better indicator of the number of carrier deficits.

However, the out-of-stock percentage is not the only indicator of good resource control. New carriers are not yet reported in SAP and are therefore not measured in this primary metric. Precautions for the consequences of new equipment projects and new product introductions will help to prevent deficits of those new carriers. A study for better forecasting methods for the expected sales and the need for new carriers can help to prevent deficits even more.

For carriers that do not have a spare stock in the technical warehouse, the out-of-stock percentage could not be measured. The recommended solutions will help to reduce the number of incidents with deficits. The actual reduction cannot be measured.

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Glossary

Bouwens model	Model used at Philips Uden to calculate needed machine and operator capacity
CDM tube	Ceramic Discharge Methalhalide tubes
Cermets	Molybdenum products
CLIP	Confirmed Line Item Performance = (1 – (number of order lines delivered tardy/total of order lines)) × 100%
Elevator oven	Oven (900 degrees) that melts assemblies together
HT oven	High temperature oven (2000 degrees) that makes the products translucent
LLS-BOM	Machine that cuts CDM tubes
Metric	Key performance indicator to focus on to achieve the overall project goal
MMP	Milestone in machine releases
MPDL	Machine and Product Documentation Lighting
Naberoven	Small oven, used for various purposes
Order line	Order from a customer for a specific product type on a specific date
PCA	Poly Crystalline Alumina
Plug	Component of SON tubes, small ring at both ends of a tube
Product group	Group of products that differs from other product groups on the carrier they take
Product platform	Group of products that differs from other product groups on production process and composition
Product type	A product type is a specific product that differs from other products on size, wattage, antenna, etc.
PSA	Plug cutting equipment
PT	Production team
R&O	Repair and maintenance
Ring	Component of T-plugs
SIKA	Machine that cuts SON tubes and assembles plugs in it
SIM	Machine that cuts SON tubes and assembles plugs in it
SON tube	High pressure sodium vapour tube
T-plug	Component of CDM tubes, consisting of a ring and a VUP, at both ends of a tube
VUP	Component of T-plugs, placed in the hole of a ring
White SON tube	High pressure sodium vapour tube spreading white light

Appendix 1. SON and CDM composition

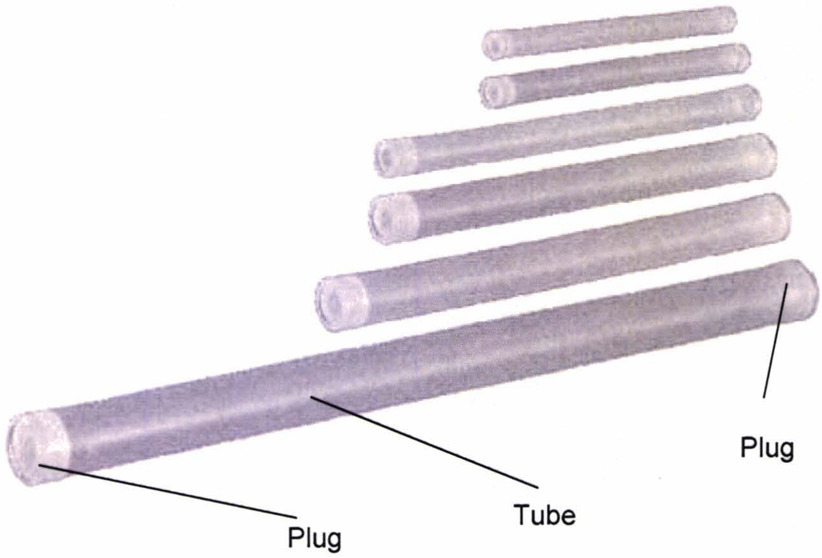


Figure A 1-1 SON product [1]

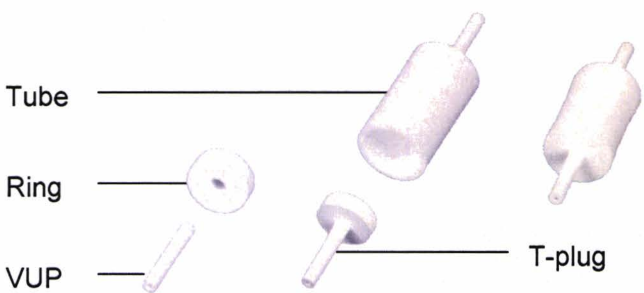


Figure A 1-2 CDM product [2]

A SON (high pressure Sodium lamp) product is a tube with a plug at both ends of the tube. A CDM (Ceramic Discharge Metal halide lamp) product consists of a tube with a T-plug at both ends of the tube. A T-plug consists of a ring and a VUP ("Ver Uitstekende Prop").

Appendix 2. Organization charts Philips Uden

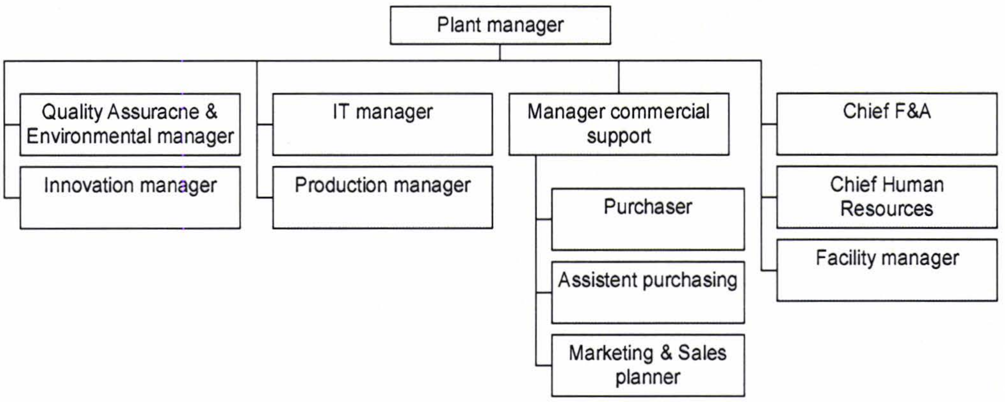


Figure A 2-1 Organization chart Philips Uden [1]

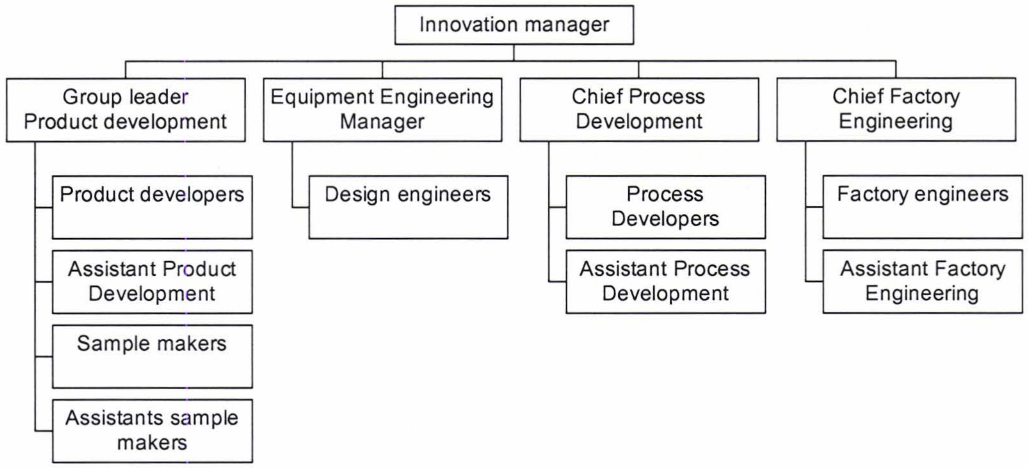


Figure A 2-2 Organization chart development department Philips Uden [1]

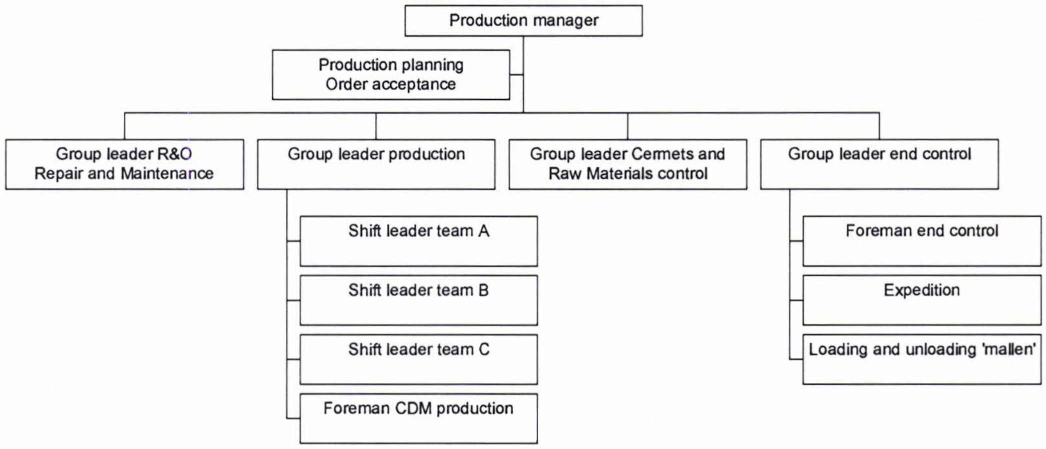


Figure A 2-3 Organization chart production department Philips Uden [1]

Appendix 3. MEDIC approach

MEDIC projects have 6 phases, which are shortly described below. [4]

Pre-MEDIC: Project charter
Focus:
- Define the process improvement opportunity and its business impact

Deliverables:
- The project charter agreed by the leader, team and management

M: Map & Measure
Focus:
- Understanding the process, the inputs and outputs and the baseline performance

Deliverables:
- Understand the problem
- Understand the process
- Benchmark information
- Definite decision on the target

E: Explore & Evaluate
Focus:
- To gain a quantitative understanding of where and how the process can be improved

Deliverables:
- Analysis of the process: root causes quantified
- Pareto chart in terms of root causes

D: Define & Describe
Focus:
- To identify, describe and quantify the solution

Deliverables:
- The verified solutions
- A process map of the improved process
- A risk analysis and corrective actions

I: Implement & Improve
Focus:
- Implementation of the planned improvement

Deliverables:
- Implementation plan
- Pilot/test of the new process
- Improved performance

C: Confirm & Control
Focus:
- A comprehensive control plan

Deliverables:
Standardization of updated procedures.
- The Control Plan
- Standard procedures
- Acceptance by the process owner/manager

Appendix 4. Description of production at Philips Uden

SON products
SON tubes consist of three components, namely one tube and two plugs. This is shown in Appendix 1. The flowchart for SON products is in Figure A 4-1. This flowchart is a starting point for the description of the production process.

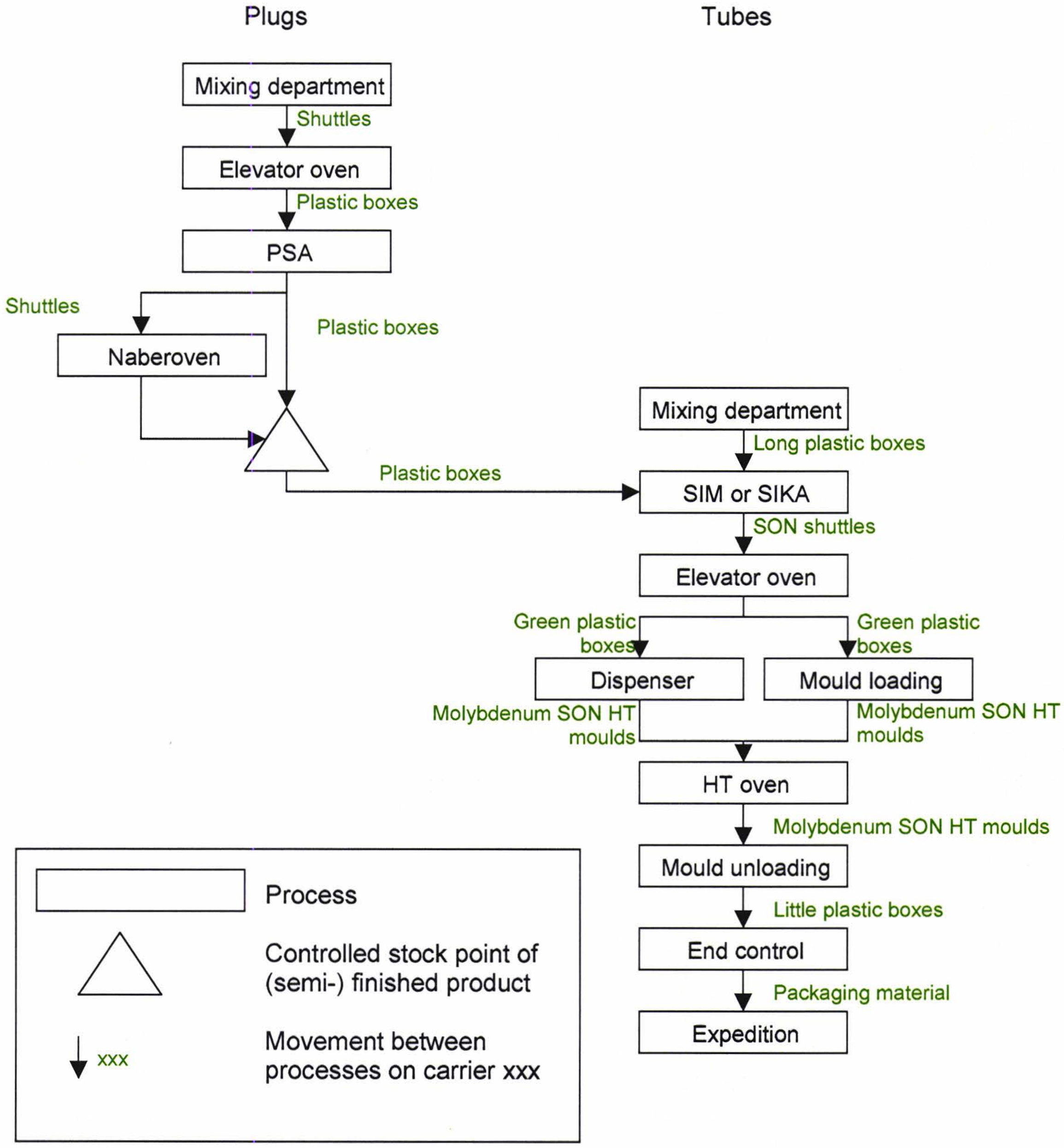


Figure A 4-1 Flowchart for SON tubes

First, the mixing department produces long tubes, of which some are cut into smaller pieces. The smaller pieces are made for plug orders; the long tubes are for tube orders.

The smaller pieces for plugs go to an oven, the elevator oven, and from there on they go to PSA, a department where the tubes are cut into small pieces and the products actually get the form of a plug. Then, some of them are heated in another oven, the Naberoven, to correct dimensions. After this the plugs are ready to be assembled in a tube and are stored in a warehouse. Other plugs go straight from PSA to the warehouse.

The long tubes from the mixing department go to the SIM or SIKA machine, which cuts the tubes into shorter tubes and puts a plug in both ends of the short tube. After this, the whole product goes into the elevator oven. The products that need an antenna go to the dispenser, where the antenna is attached to the product.

The products without antenna go straight into the high temperature oven (HT oven). The tubes with an antenna go there after the dispenser treatment. Before the HT oven the products are loaded in an HT mould. For the products without antenna, this is done at a special loading and unloading depa rtment, while the products with an antenna are loaded into an HT mould at the dispenser.

After the HT oven the moulds are unloaded again and the products go to the end control department, where the products are checked on some quality issues. Finally, the products go to the warehouse.

CDM products
This process differs from the process for SON tubes because CDM products have more components. They need a tube, a ring and a VUP instead of a tube and a plug. This is shown in Appendix 1. In the description below, only the steps that differ from the SON production process are discussed. A graphical representation of the CDM production process is in Figure A 4-2.

From the mixing department, the tubes for rings and VUPs go into the elevator oven and the rings are then cut into the form of a ring at PSA. The VUPs are treated in the Naberoven before they go to the PSA department. After PSA, some of the rings and VUPs are first heated in the Naberoven and go to a warehouse after this treatment. The other rings and VUPs go straight to the warehouse. So, the rings and VUPs have more or less the same process steps as plugs.

The process for CDM tubes differs from SON tubes in that the CDM tubes are processed on the LLS-BOM machine. This machine only cuts the long tubes into pieces and does not put a ring and VUP into the tube.

In a later stadium, a ring and a VUP are taken from stock and assembled by an operator. The assembly of the ring and VUP is called a T-plug and is processed in the elevator oven on a dotted or flat tile. This is necessary to melt the two parts together. There are two different T-plugs, namely T-plug 1 and T-plug 2.

When T-plug 1 comes out of the elevator oven, it is put into one end of a tube. The tube with on one end T-plug 1 is also processed in the elevator oven on a tile. After this, a T-plug 2 is put into the other end of the tube as well and this complete product with two T-plugs goes into the elevator oven again. This is the last treatment in the elevator oven.

From here on, the process is the same as for SON tubes without an antenna. So, now the products go on special CDM HT moulds in the HT oven and are then checked by the end control department.

White SON products

White SON tubes form a relatively small product platform that is produced in both the SON and the CDM department and the production method is similar to that for SON products except for the SIM department. Normally, in this department the SIM or SIKA machine cuts long tubes into pieces and puts a plug in both ends of the tube. However, for white SON tubes, the long tubes are cut at LLS-BOM and the plugs are put into the tube manually at the CDM department.

Cermets

Cermets are another product group that is produced at Philips Uden. These products will not be part of the analysis because the cermets are completely separate from the rest of the plant.

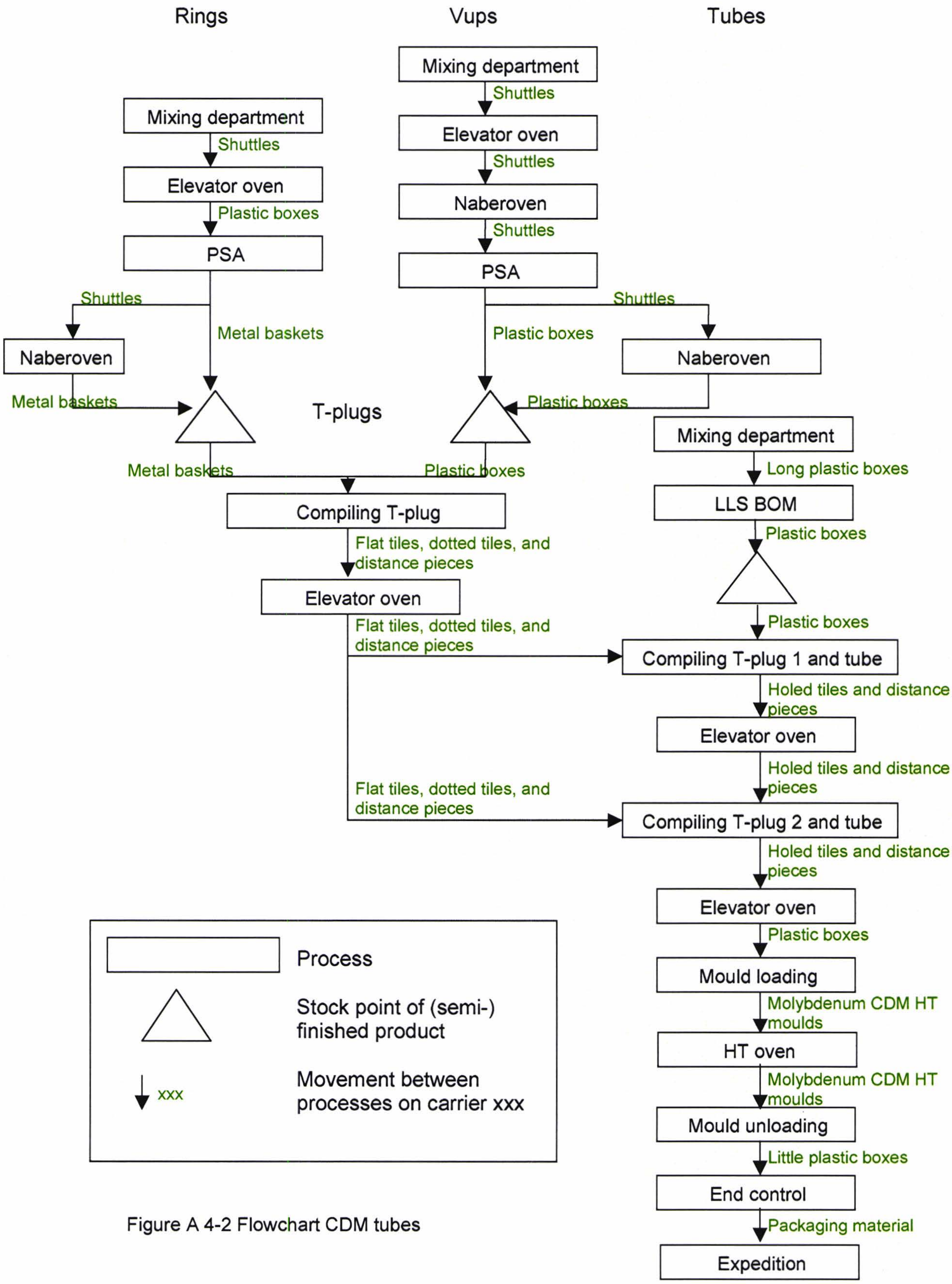


Figure A 4-2 Flowchart CDM tubes

Appendix 5. Compiled nozzles

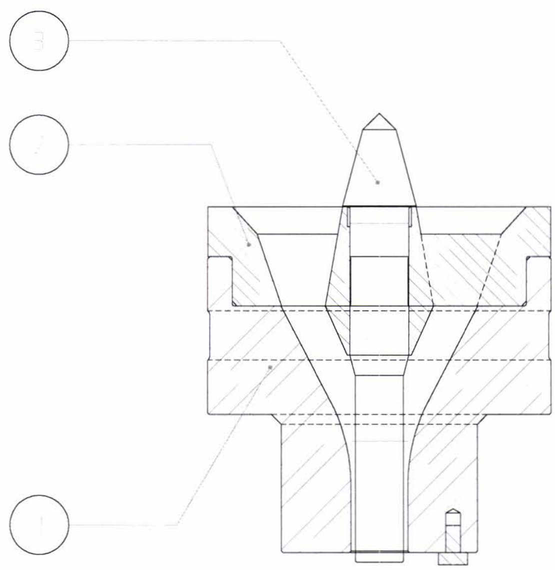


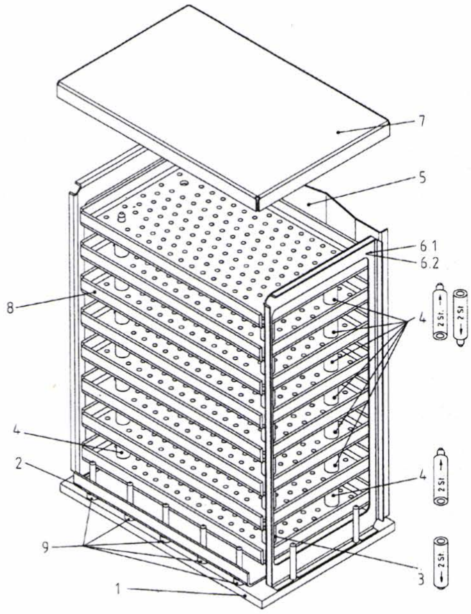
Figure A 5-1 Example of a nozzle

1 = Die
2 = Punch holder
3 = Extruding punch

The die determines the outer tube width. The punch holder holds the extruding punch, which determines the inner diameter of the tube. The die and the extruding punch together determine the wall thickness of the tube.

Figure A 5-2 Picture of a nozzle

Appendix 6. CDM HT moulds



1. Part of bottom sheet
2. Part of bottom sheet
3. Short distance pen
4. Distance pen
5. Side sheet
6. Head sheet
7. Cover
8. Tray
9. Part of bottom sheet

Figure A 6-1 Technical drawing of CDM HT mould

	35W mould	70W mould	150W mould
Number of products per mould	1960	1330	560
35W trays	7		
70W trays		7	
150W trays			5
Distance pens 32 mm	26	22	
Short distance pens 32 mm	2	2	
Distance pens 44 mm			14
Short distance pens 44 mm			2
Covers	1	1	1
Head sheets	2	2	2
Side sheets	2	2	2
Bottom sheets	1	1	1

Table A 6-1 Components per CDM HT mould

Figure A 6-2 Picture of two loaded CDM HT moulds

Appendix 7. SON HT moulds

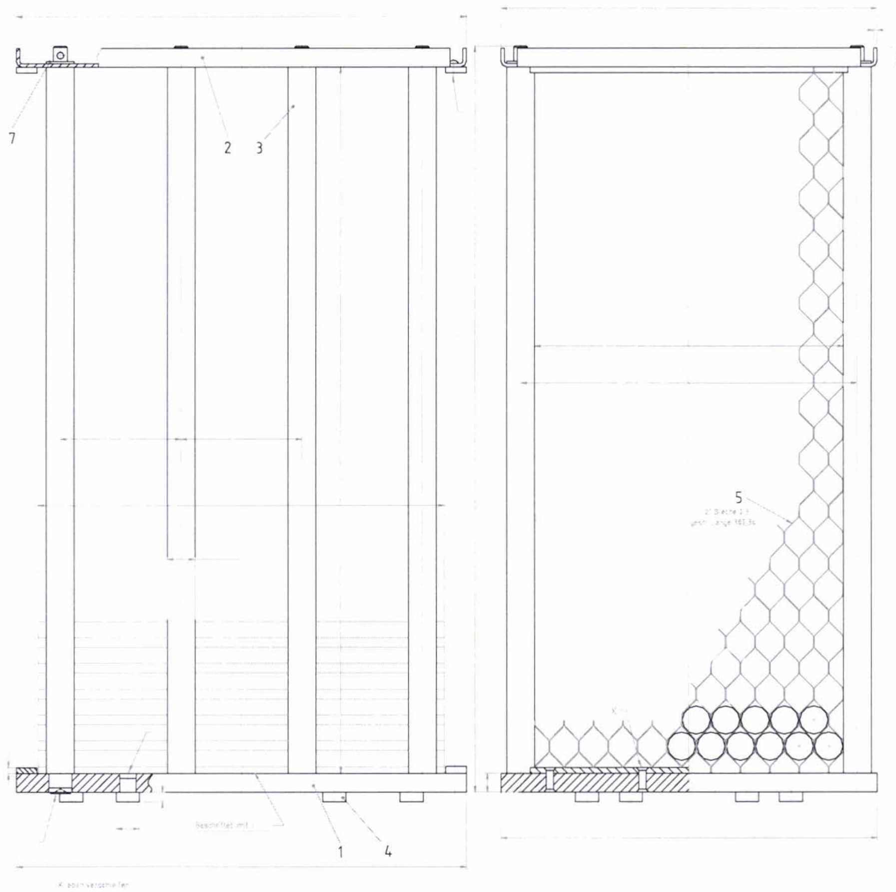


Figure A 7-1 Technical drawing of a SON HT mould

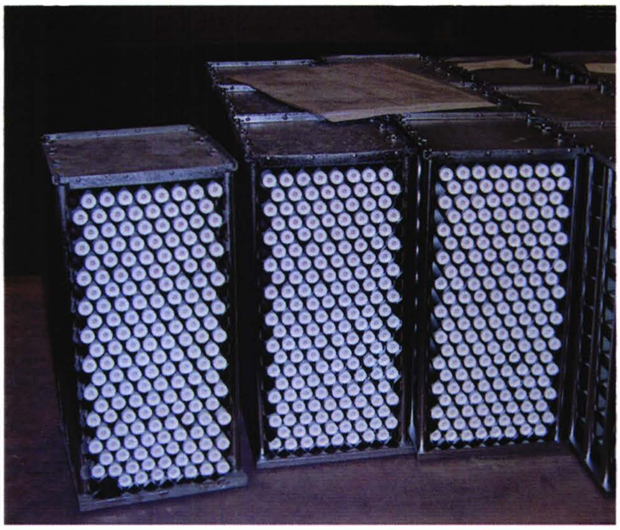


Figure A 7-2 Picture of three loaded SON HT moulds

Appendix 8. Cause diagrams

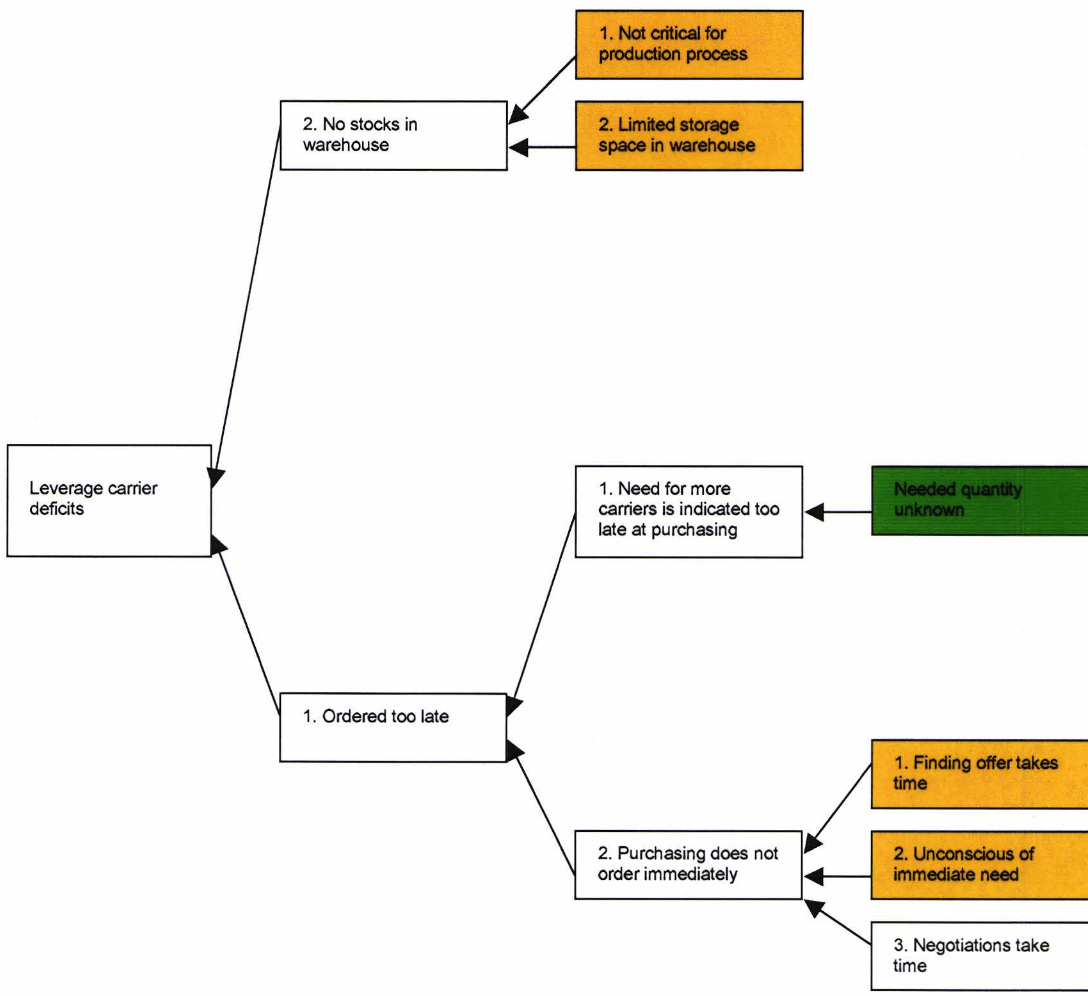


Figure A 8-1 Cause diagram for leverage carrier deficits

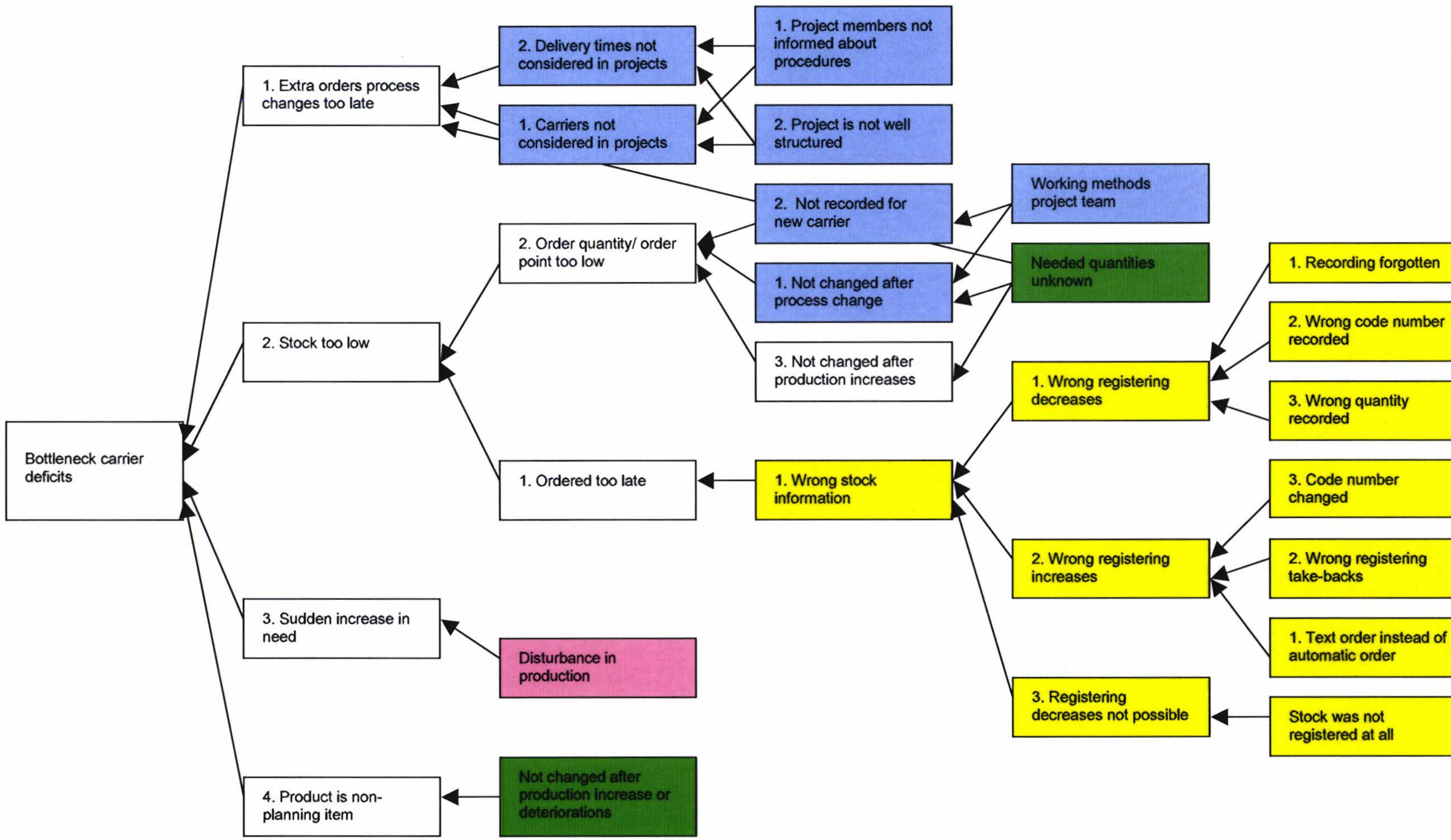


Figure A 8-2 Cause diagram for bottleneck carrier deficits

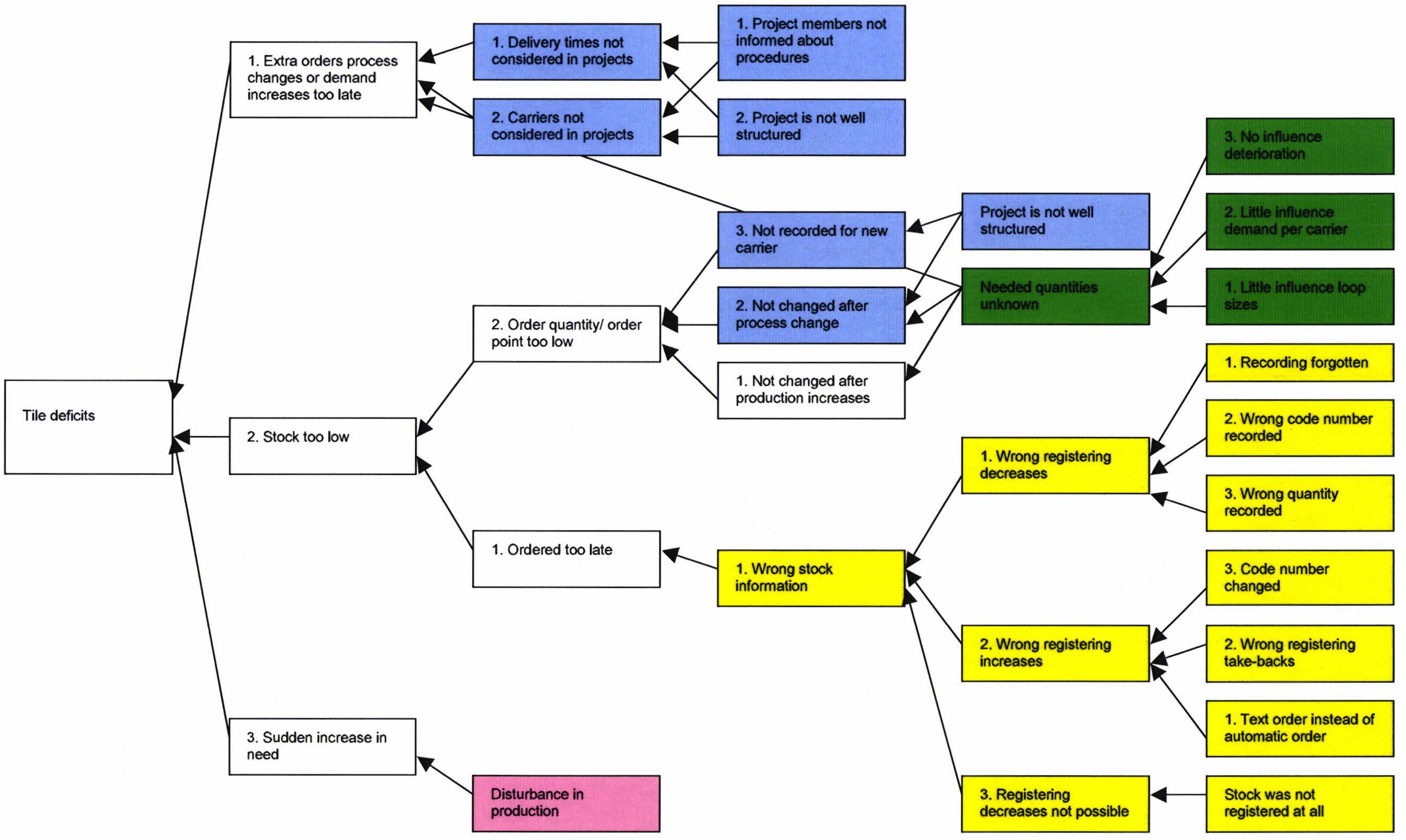


Figure A 8-3 Cause diagram for tile deficits

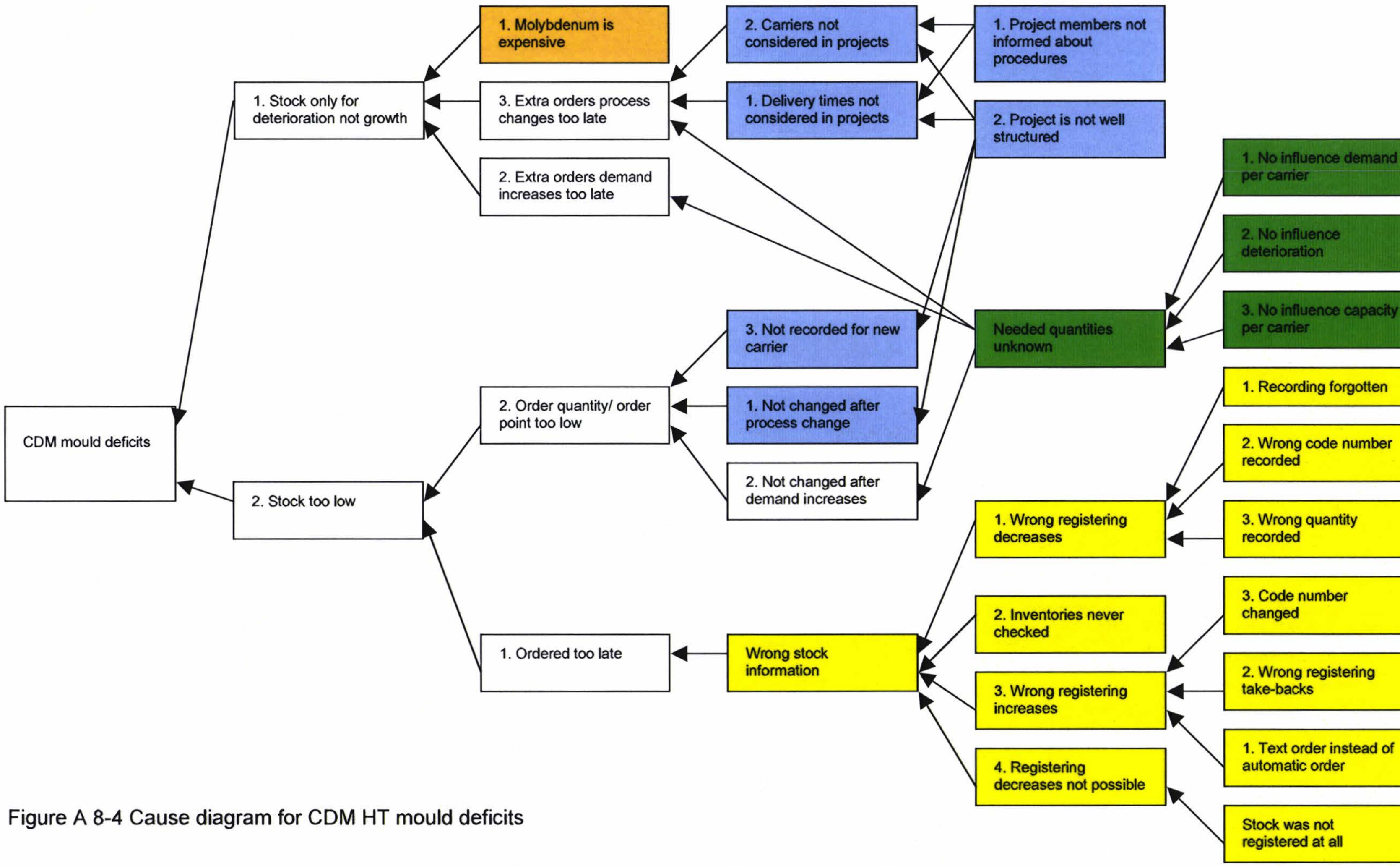


Figure A 8-4 Cause diagram for CDM HT mould deficits

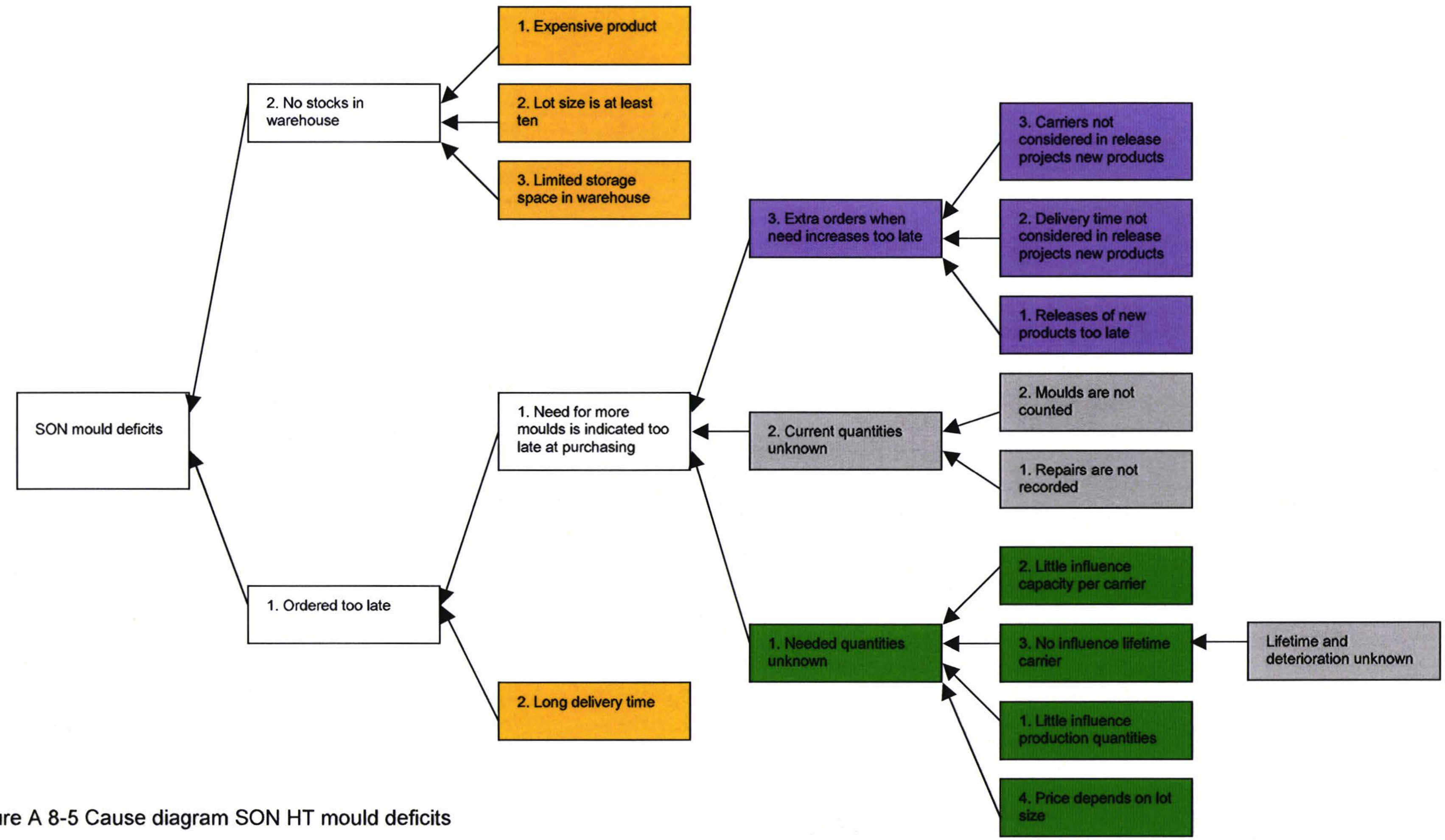


Figure A 8-5 Cause diagram SON HT mould deficits

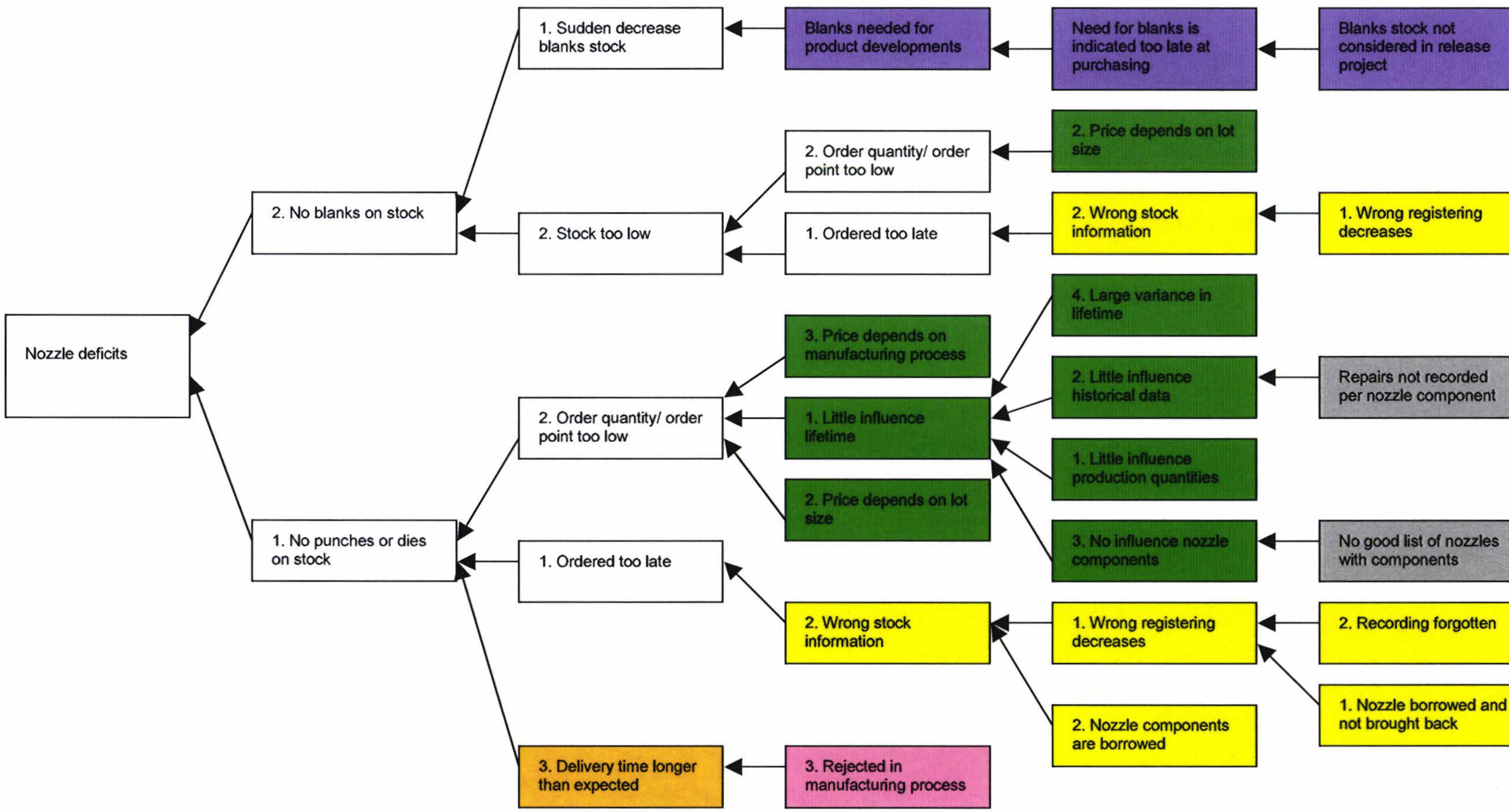


Figure A 8-6 Cause diagram nozzle deficits

Appendix 9. Analysis of solutions for inventory accuracy

	Bar coding	Moment related counting	ABC cycle counting	Process cycle counting	Restricted access	Removing unregistered items	Changing units of measure
Costs in euros of implementation	€ 3.000 [11]	€ -	€ -	€ -	€ 5.000	??	€ -
Score on increase in correctness of information in terms of inventory accuracy percentage for critical parts	1	3	4	2	3	2	3
Resulting accuracy	85%	91%	92%	87%	92%	86%	94%
Efforts of implementation (man hours)	40	1	8	1	20	10	10
Efforts of maintaining (man hours)	2	1,5	2	1,5	5	0	0,5

Table A 9-1 Weights and scores of criteria and solutions inventory accuracy

The current inventory accuracy is estimated on the basis of a sample of 86 items in the warehouse and is 84%.

The costs of removing unregistered items from the technical warehouse cannot be estimated yet, because there are various options possible for this solution.

Appendix 10. Lists of parameters

Parameters in models for strategic carriers

a_i	Lifetime of carriers in carrier group *i* expressed in number of uses
b_i	Percentage of carriers in group *i* breaking per period
B	Fixed number of loop for CDM assembly (tiles)
cv_i	Coefficient of variation for carrier group *i* (standard deviation/average sales per week)
$C_i^{\min}$	Minimum lot size in number of carriers for carrier group *i*
f_i	Average number of carried products divided by number of products that can be carried by a carrier of carrier group *i*
$F_i(t)$	Forecast of demand in end products per week for product group *i* in period *t* made in period 0
γ_i	Average increase or decrease of the price of carrier group *i* per week
h_1	Holding cost percentage in euros per period of end products
h_2	Holding cost percentage in euros per period for carriers
k	Safety factor for maximum production, related to the target for the CLIP indicator
k_1	Costs in euros per month for having one operator working in dayshift
k_3	Costs in euros per month for having one operator working in three shifts
k_5	Costs in euros per month for having operators working in five shifts
λ_i	Weighted average throughput time for product group *i* in days
LT_i	Delivery time in weeks for a carrier in carrier group *i*
$P_{year}^{\max}$	Maximum aggregate production in number of end products per week in a year
q_i	Number of products that a carrier in carrier group *i* can carry simultaneously
$S_i(t)$	Actual sales in number of end products for group *i* in period *t*
$U_i^{\max}$	Maximum number of uses per week of a carrier in carrier group *i*
v_i	Value in euros of products of product group *i*
$x_i(t)$	Number of carriers of carrier group i that are already planned to arrive in period *t*

Parameters in model for nozzles

h_2	Holding cost percentage for nozzles in euros per week
μ	Average demand of components per week
L	Delivery time in weeks of new components
$p(Q)$	Price in euros for one nozzle when purchasing order quantity Q

Appendix 11. Inputs and results for bottleneck and leverage carriers

	S	1,15 × S	q	n
Metal baskets	214.753	246.965	900	274

Table A 11-1:The results of the simple model for leverage carriers

	S	1,20 × S	q	n
Shuttles	327.590	393.108	140	2.808
Distance pieces	214.753	257.704	20	12.885

Table A 11-2:The results of the simple model for bottleneck carriers

	Current number	Number needed	Order point
Small	1957	1960	200
Medium	501	500	50
Large	362	370	40
Total	2.820	2.830	

Table A 11-3: Shuttles needed per sort

	Current number	Number needed	Order point
25mm	5.800	5.710	570
30mm	1.900	1.870	190
40mm	1.500	1.480	150
45mm	2.300	2.270	230
55mm	1.600	1.580	160
Total	13.100	12.910	

Table A 11-4: Distance pieces needed per sort

Appendix 12. Breaking down of carriers

The breaking of carriers is determined by two factors, namely the lifetime and the deterioration rate. The lifetime is the average number of times that a certain carrier sort can be used before it breaks. The deterioration rate is independent of the number of times that a carrier is used. It is the percentage of carriers that breaks per period.

For SON HT moulds, the breaking data have been found from an analysis of repair data and measurements. For CDM HT moulds and tiles, the data are estimated from interviews with operators and foremen.

SON HT moulds
A SON HT mould may have break down for two reasons. The first is that the width of the mould is too large and the second is that a certain part of the mould has broken off. From the discussion below the deterioration parameters in Table A 12-1 are found.

Carrier group	5	6	7	8	9
a_i	270	276	541	405	420
b_i	0,0016	0,0016	0,0016	0,0016	0,0016

Table A 12-1 Breaking parameters for SON HT moulds

The belly and skewness together determine the width of the mould. The maximum width of a mould can be 178 mm, whereas the original width is 158 mm. The belly is the deviation in millimetres between the bottom or top and the middle of the mould and the skewness is the deviation in millimetres between bottom and top. This means that the mould cannot be used anymore if belly plus skewness is equal to 20 mm.

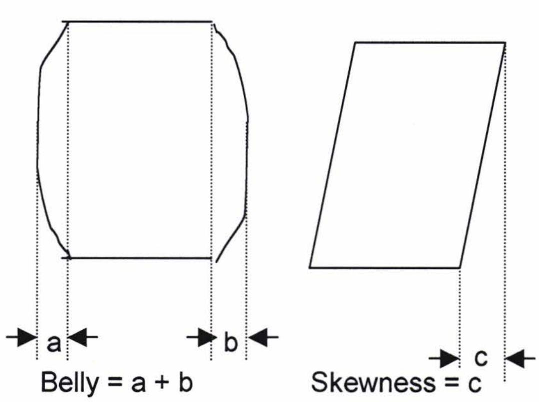


Figure A 12-1 Belly and skewness

There are 10 (5 150W and 5 400W) moulds that are used in production and of which the usage is recorded. Twice a year, the belly and the skewness of these moulds are recorded. These data are used to come to conclusions on the lifetime of SON HT moulds.

The data about the 400W test moulds are statistically analysed. The hypothesis is that a relationship exists between number of uses and the sum of the belly and the skewness. This hypothesis was tested with a linear regression analysis. This analysis pointed out that the P-value for the relationship between belly + skewness and number of uses is less than 0,01, indicating a statistically significant relationship at the 99% confidence level. The correlation coefficient is equal to 0,80546, which indicates a moderately strong relationship between belly + skewness and number of uses. The increase in width can be calculated as follows:

Equation 66: Belly + skewness = - 0,313787 + 0,037524 × number of uses

Since for 150W moulds, the P-value is also less than 0,01, there is a statistically significant relationship between belly + skewness and number of uses at the 99% confidence level as well. The correlation coefficient for this analysis is even higher, namely 0,907705, indicating a relatively strong relationship. The increase in width is calculated by the following formula:

Equation 67: Belly + skewness = - 0,441755 + 0,0739003 × number of uses

For the other sorts of moulds, there are no test records. This means that the deterioration for these moulds is calculated on the basis of the records above. 150W moulds have more holes than 400W moulds. The hypothesis is that the number of times that a carrier can be used is dependent of the number of holes in the mould. This is evaluated by adding the number of holes in the mould as an independent variable to the regression analysis.

Again, the P-value is less than 0,01, which leads to the conclusion that there is a relationship between both independent variables and the belly + skewness. So, for the other moulds, the following formula is used:

Equation 68: Belly + skewness = - 4,84639 + 0,0126773 × holes + 0,0560552 × number of uses

To determine the number of times that a carrier can be used, the number of holes must be known. These numbers and the corresponding lifetime data are in Table A 12-2. Of course, this is not completely right, since it means that 600W and 1000W moulds could be used less than 400W moulds. However, it is the most appropriate approximation for this lifetime problem.

Mould	Holes	Average # uses
70W	765	270
150W	442	276
400W	260	541
600W	168	405
1000W	100	420

Table A 12-2: Number of holes and lifetime per mould

The repair data of damaged carriers are also recorded. It is known how many carriers go on the repair shelf and how many come back for use in production. When removing the repair data of the moulds that have become more than 20mm in width, on average 8% of the carriers go on the repair shelf in one year. This means that the deterioration rate is 0,0016 per week.

CDM HT mould components

CDM HT mould	Lifetime in number of uses	Deterioration rate per week
35W trays	Infinite	0,0005
70W trays	Infinite	0,0005
150W trays	Infinite	0,0005
Distance pens 32 mm	Infinite	0,001
Short distance pens 32 mm	Infinite	0,001
Distance pens 44 mm	Infinite	0,001
Short distance pens 44 mm	Infinite	0,001
Covers	200	0,002
Head sheets	200	0,002
Side sheets	300	0,002
Bottom sheets	400	0,002

Table A 12-3 Estimated deterioration data for CDM HT mould components

CDM tiles

CDM tile	Lifetime in number of uses	Deterioration rate per week
Dotted tile	200	0,002
Flat tile	500	0,002
Holed tile 361 holes	300	0,002
Holed tile 225 holes	300	0,002
Holed tile 144 holes	150	0,002

Table A 12-4 Estimated deterioration data for CDM tiles

Appendix 13. Inputs and results for simple model for strategic carriers

This appendix gives an overview of the parameter values for the simple model for strategic carriers. CDM HT moulds contain several parts that are composed together every time the mould is loaded. An overview of the parts per mould is in Table A 6-1.

The parameter values for the model described in section 5.2.2, are in Table A 13-1, Table A 13-2, and Table A 13-4. The arrivals of new tiles are in Table A 13-5.

SON HT moulds

SON HT mould	q_i	cv_i	a_i	b_i	$A_i(0)$	f_i	$C_i^{\min}$	λ_i (days)
70W	1367	0,174	270	0,0016	86	0,94	10	3,32
150W	903	0,159	276	0,0016	103	0,92	10	3,76
400W	265	0,171	541	0,0016	408	0,87	10	3,45
600W	168	0,643	405	0,0016	112	0,91	10	3,30
1000W	137	0,458	420	0,0016	117	0,88	10	4,43

Table A 13-1 Parameter values for SON HT moulds

CDM HT mould components

CDM HT mould components	Index *i*	Index *j*
35W trays	2	1
70W trays	1+3	2
150W trays	4	3
Distance pens 32 mm	1+2+3	4
Short distance pens 32 mm	1+2+3	5
Distance pens 44 mm	4	6
Short distance pens 44 mm	4	7
Covers	1+2+3+4	8
Head sheets	1+2+3+4	9
Side sheets	1+2+3+4	10
Bottom sheets	1+2+3+4	11

Table A 13-2 CDM HT mould components

Index *j*	q_i	cv_i	a_i	b_i	$A_i(0)$	f_i	$C_i^{\min}$	λ_i (days)
1	280	0,206	∞	0,0005	265	1	33	3,15
2	190	0,145	∞	0,0005	822	1	33	3,09
3	112	0,162	∞	0,0005	472	1	49	3,23
4	68	0,134	∞	0,001	16.775	1	100	3,08
5	823	0,134	∞	0,001	1765	1	100	3,08
6	40	0,162	∞	0,001	5080	1	100	3,23
7	280	0,162	∞	0,001	876	1	100	3,23
8	1283	0,125	200	0,002	145	1	10	3,08
9	642	0,125	200	0,002	289	1	100	3,08
10	642	0,125	300	0,002	447	1	100	3,08
11	1283	0,125	400	0,002	242	1	8	3,08

Table A 13-3 Parameter values for CDM HT mould components

CDM tiles

CDM tile	Index *i*	q_i	cv_i	a_i	b_i	$A_i(0)$	f_i	$C_i^{\min}$	λ_i (days)	B
Dotted tile	1	209	0,158	200	0,002	611	1	32	5,33	4
Flat tile	2+3+4	224	0,127	500	0,002	1095	1	32	5,33	4
Holed tile 361 holes	2	332	0,206	300	0,002	469	1	40	7,63	4
Holed tile 225 holes	1+3	209	0,145	300	0,002	1105	1	30	7,63	4
Holed tile 144 holes	4	130	0,162	150	0,002	571	1	55	7,63	4

Table A 13-4 Parameter values for tiles

		Number of tiles arriving for				
Period	Month	Dotted tiles	Flat tiles	Holed tiles, 361 holes	Holed tiles, 225 holes	Holed tiles, 144 holes
3	May 2005					55
8	June 2005					55
12	July 2005				30	
13	August 2005					55
14	August 2005				30	
16	September 2005				30	
18	September 2005		32		30	55
20	October 2005		32		30	
21	October 2005	32				
22	October 2005				30	
23	October 2005		32			
24	October 2005				30	55
25	November 2005	32	32		30	
28	November 2005		32		30	
29	December 2005	32		40	30	55
30	December 2005		32			
32	December 2005		32		30	
33	January 2006	32			30	
34	January 2006		32			55
35	January 2006				30	
37	January 2006	32	32	40		
38	February 2006				30	
39	February 2006		32		30	55
41	February 2006	32			30	
42	March 2006		32			
43	March 2006				30	
44	March 2006	32	32	40		55
45	March 2006				30	
46	April 2006				30	
48	April 2006	32				
49	April 2006		32		30	55

Table A 13-5 Arrivals for tiles on basis of forecasts

Appendix 14. Inputs and results for joint optimisation of inventories and carriers

For the model described in 5.2.3, additional parameters are necessary. These parameter values are in Table A 14-1, Table A 14-3, and Table A 14-5. The accompanying figures show the inventories kept and Table A 14-4 and Table A 14-6 show the orders that must be made for the CDM HT mould components and the tiles. For the SON HT moulds, the model does not purchase any carriers.

SON HT mould	v_i (€)	Standard deviation value	cv_i	$p_i(0)$	$R_i(0)$	LT_i(weeks)
70W	0,301	0,150	0,174	€ 2800	6	26
150W	0,463	0,122	0,159	€ 2800	5	26
400W	0,693	0,196	0,171	€ 2700	7	26
600W	1,795	0,699	0,643	€ 2500	2	26
1000W	2,479	0,680	0,458	€ 2400	3	26

Table A 14-1 Parameter values for the joint optimisation of inventories and carriers for SON HT moulds

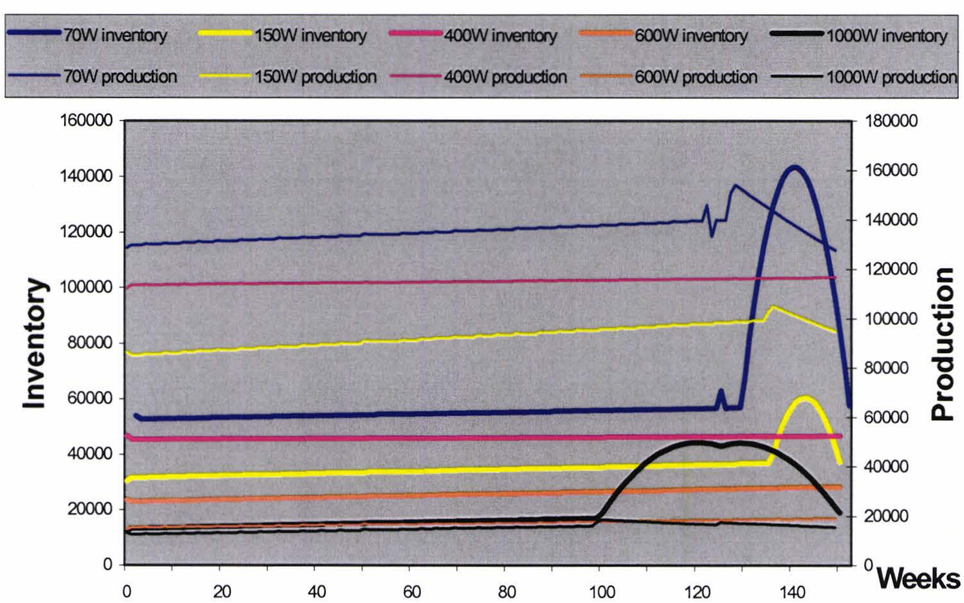


Figure A 14-1 Inventories and production for SON end products on the basis of joint optimisation of carriers and inventories

CDM product	Index i	cv_i	v_i (€)	Standard deviation value	q_i (only for tiles)
70W tubes 1	1	0,158	0,653	0	209
35W tubes	2	0,206	0,528	0	332
70W tubes 2	3	0,179	0,628	0,056	209
150W tubes	4	0,162	1	0	130

Table A 14-2 Parameter values for CDM products

CDM HT mould component	Index j	p_j (0)	A_j (0)	LT_j (weeks)
35W trays	1	€ 342	265	26
70W trays	2	€ 297	822	26
150W trays	3	€ 297,50	472	26
Distance pens 32 mm	4	€ 13,55	16.775	26
Short distance pens 32 mm	5	€ 16,70	1765	26
Distance pens 44 mm	6	€ 13,40	5080	26
Short distance pens 44 mm	7	€ 18,90	876	26
Covers	8	€ 152	145	26
Head sheets	9	€ 78,48	289	26
Side sheets	10	€ 107,96	447	26
Bottom sheets	11	€ 1140	242	26

Table A 14-3 Parameters for the joint optimisation of inventories and carriers for CDM HT mould components

Period	Month	Number of covers arriving	Number of head sheets arriving
26	November 2005	49	
27	November 2005		100

Table A 14-4 Arrivals for CDM HT mould components on the basis of joint optimisation of carriers and inventories

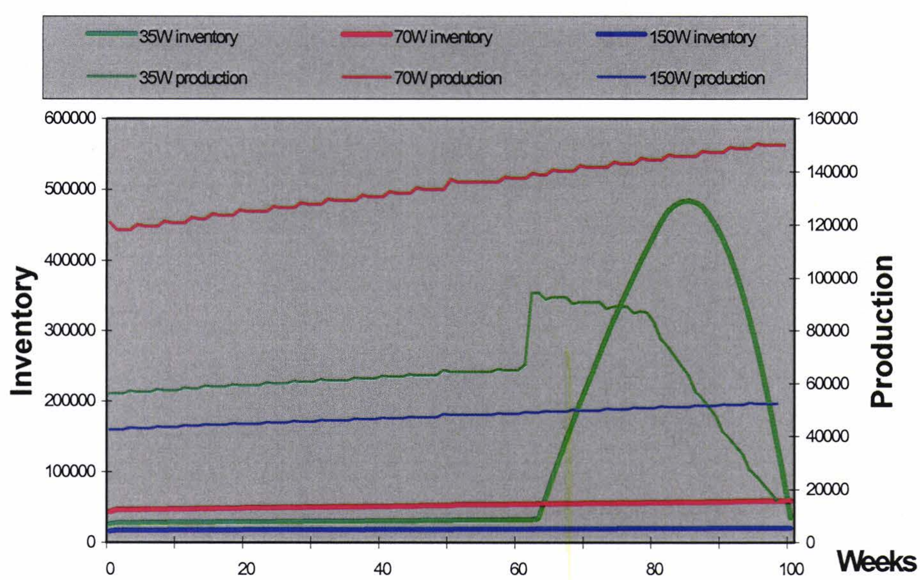


Figure A 14-2 Inventories and production for CDM end products on the basis of joint optimisation of CDM HT mould components and inventories

CDM tile	p_j (0)	A_j (0)	B	LT_j (weeks)
Dotted tile	€ 317	611	4	12
Flat tile	€ 70,40	1095	4	12
Holed tile 361 holes	€ 170	469	4	12
Holed tile 225 holes	€ 141,80	1105	4	12
Holed tile 144 holes	€ 120	571	4	12

Table A 14-5 Parameters for the joint optimisation of inventories and carriers for tiles

Period	Month	Number of dotted tiles arriving	Number of flat tiles arriving	Number of holed tiles, 144holes arriving
24	October 2005		35	
28	November 2005		32	
31	December 2005		32	
37	January 2006		33	
42	March 2006	90		
44	March 2006		35	
49	April 2006		36	
54	May 2006		32	
55	June 2006		32	
57	June 2006		37	
67	September 2006		95	55

Table A 14-6 Arrivals for tiles on the basis of joint optimisation of carriers and inventories

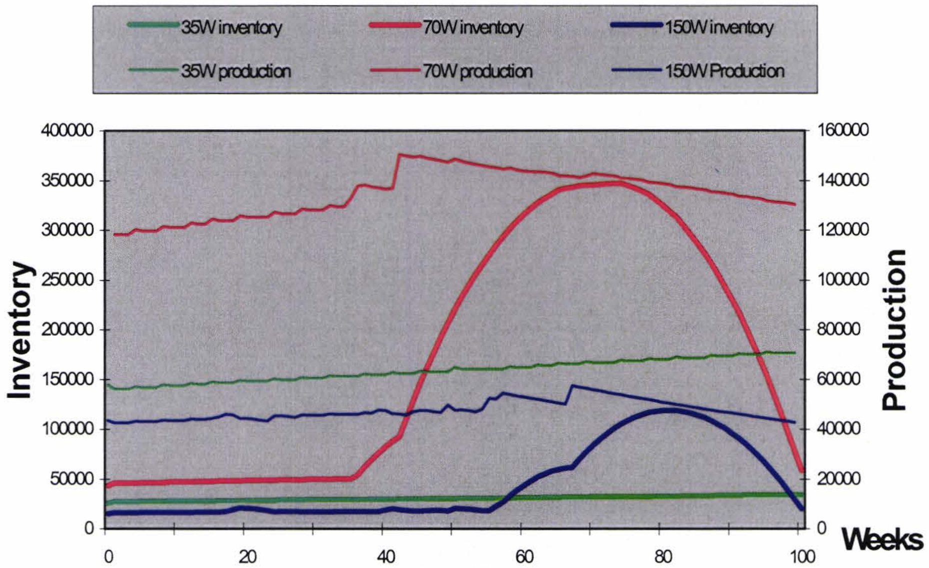


Figure A 14-3 Inventories and production for CDM end products on the basis of joint optimisation of tiles and inventories

Appendix 15. Operator effect on throughput-time

To investigate the effect of having operators in three or five shifts on the throughput-time, a simulation of the mould loading and unloading department is done. The moulds go through three steps in this department, namely loading, processing in the oven, and unloading. Between these steps the moulds may be in a queue to go the next step. This is represented by Figure A 15-1.

Operators are necessary to load and unload the moulds. These operators become available after having loaded or unloaded the mould. The moulds become available again after the unloading step.

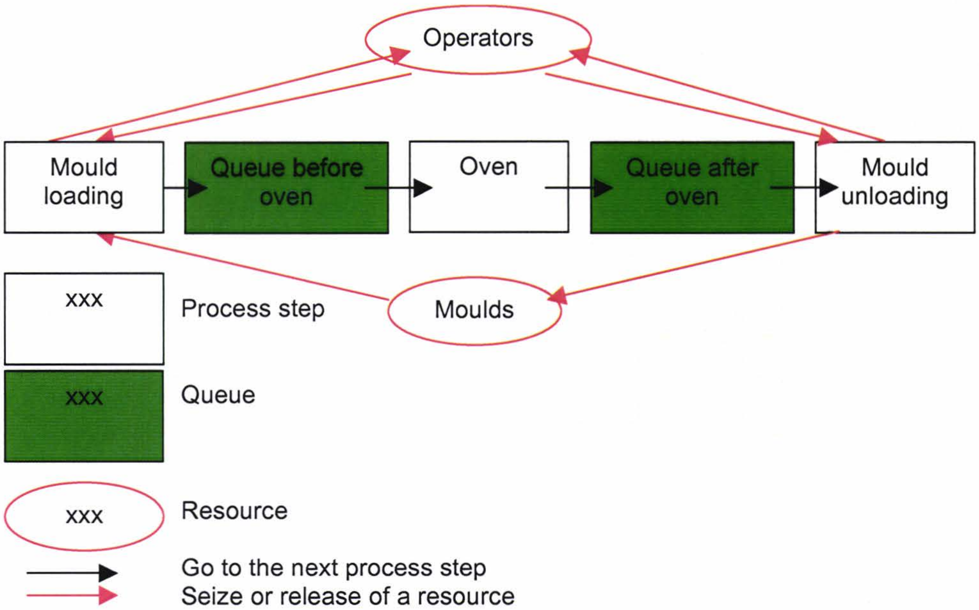


Figure A 15-1 The process of loading and unloading moulds

The matter under investigation is the average throughput-time for moulds from mould loading to mould unloading under different working times for the operators. In Arena, the throughput-times of the moulds are recorded for three situations.

In the first situation, operators had a working schedule of 5 days of 8 hours and next 2 days of 0 hours. In the second situation, simulating the work in 3 shifts, the schedule was 5 days of 24 hours during which the capacity was 1/3 of the capacity in the first situation and 2 days of 0 hours. In the third situation, simulating 5 shifts, the schedule was 7 days of 24 hours with a capacity of 1/5 of the capacity in the first simulation.

A warm-up period of two weeks was used to cope with start-up effects and the total time of the simulation was 20 weeks.

The results of the simulation are in Table A 15-1. The second column shows the throughput-time that was found in the simulation. The values in the third columns are calculated by dividing the throughput-time in the simulation by the throughput-time in the dayshift model. This indicates how the throughput-times of working in 3 or 5 can be approximated.

Model	Throughput-time	Relation to current throughput-time
Dayshift	2,5700 days	1
3 shifts	2,1227 days	0,8260
5 shifts	1,0678 days	0,4155

Table A 15-1 Results of throughput-time simulation

With the values in the third column of Table A 15-1, the throughput-time for each carrier sort can be calculated for the three possibilities.

SON HT mould	Current throughput-time	Throughput-time in dayshift (days)	Throughput-time in 3 shifts (days)	Throughput-time in 5 shifts (days)
70W	3,32	3,32	2,74	1,38
150W	3,76	3,76	3,11	1,56
400W	3,45	3,45	2,85	1,43
600W	3,30	3,30	2,73	1,37
1000W	4,43	4,43	3,66	1,84

Table A 15-2 Throughput-times used in model with operators

Table A 15-3 shows the parameters used in the model with operators included, namely the costs in euros of one operator per month.

	Operator working in	Costs per month
k_1	Dayshift	€ 2.383
k_3	3 shifts	€ 2.908
k_5	5 shifts	€ 3.017

Table A 15-3 Costs of operators

Appendix 16. Input and results for nozzle model

Die 7622-681-39764 had a demand of 9 in a period of 122 weeks, so λ = 0,07377. The price for one die is € 1.879. The prices and the costs for the various order quantities are in Table A 16-1. An order quantity of 3 is selected.

With a delivery time of 10 weeks, the performance levels are calculated as in Table A 16-2. The base stock level selected is 4, since here the stock out frequency drops under 0,001 for the first time.

Q	P	C
1	€ 1.879	€ 2.039
2	€ 1.693	€ 1.982
3	**€ 1.555**	**€ 1.953**

Table A 16-1 Costs of the alternatives for order quantities for die 7622-681-39764

S	$\overline{A}$
1	0,07160
2	0,01559
3	0,00267
4	**0,00037**
5	0,00004

Table A 16-2 Stock out frequencies for base stock levels for die 7622-681-39764

Punch 7222-701-05681 had a demand of 3 in a period of 122 weeks, so λ = 0,02459. The price for one punch is equal to its value and is € 438. The prices and the costs for the various order quantities are in Table A 16-3. An order quantity of 1 is chosen.

With a delivery time of 10 weeks, the performance levels are as in Table A 16-4. A base stock level of 3 is selected, since here the stock out frequency drops under 0,001 for the first time.

Q	P	C
1	**€ 438**	**€ 550**
2	€ 390	€ 590
3	€ 354	€ 626

Table A 16-3 Costs of the alternatives for order quantities for punch 7222-701-05681

S	A
1	0,02571
2	0,00206
3	**0,00013**
4	0,00001
5	0,00000

Table A 16-4 Stock out frequencies for base stock levels for punch 7222-701-05681

Appendix 17. Procedure acquisition and release production means

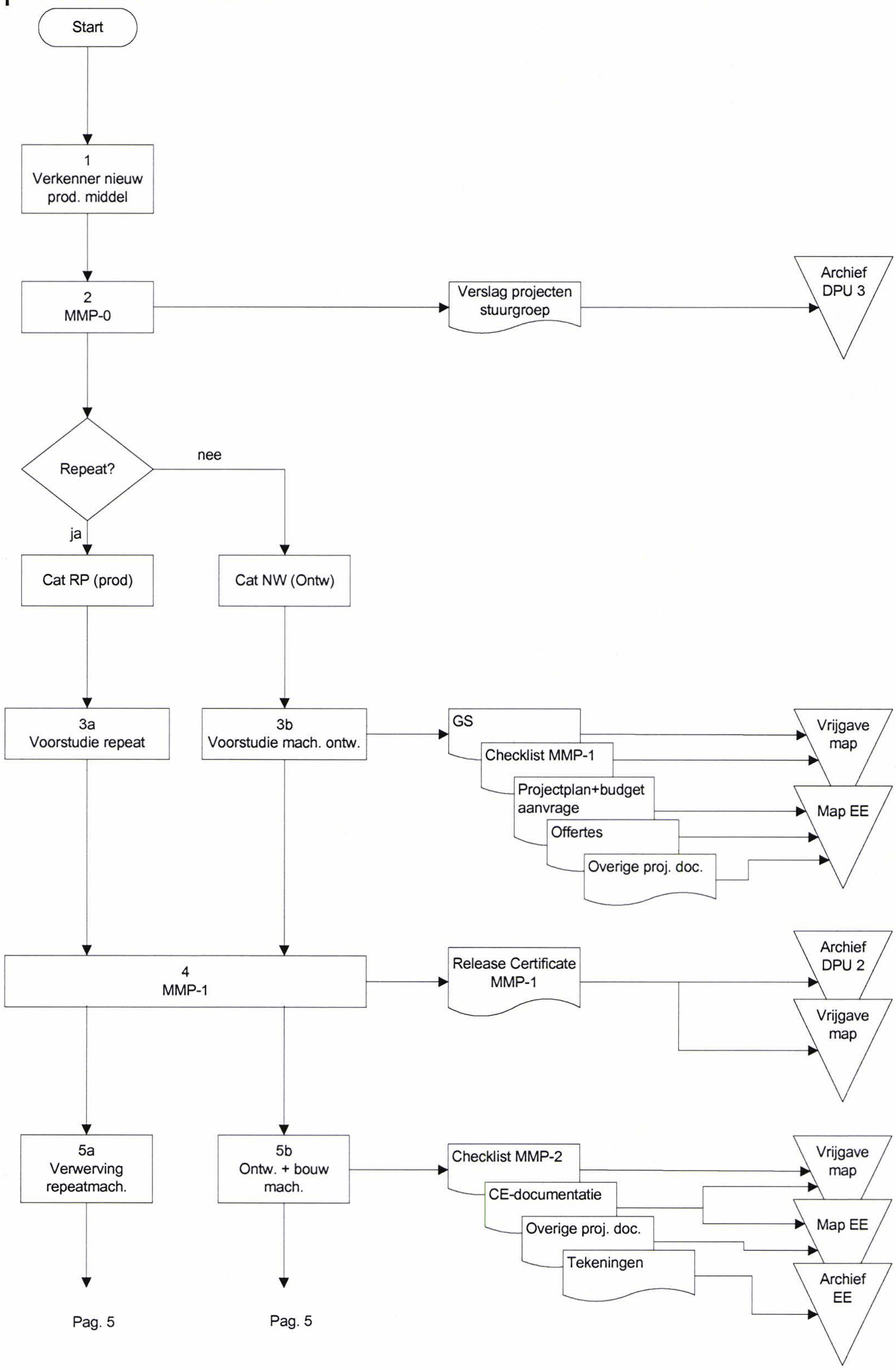


Figure A 17-1 Part one of the procedure flowchart [22]

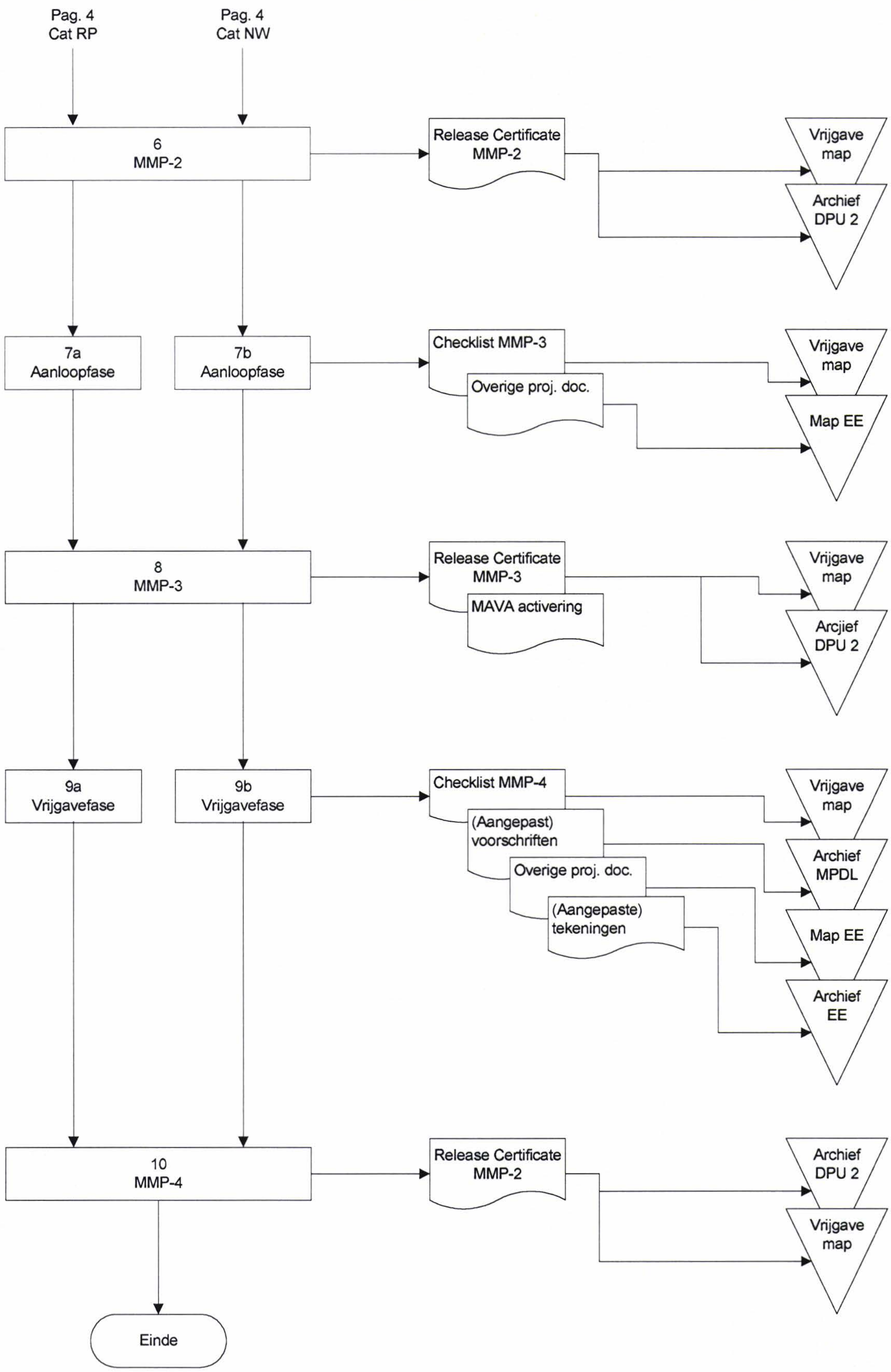


Figure A 17-2 Part two of the procedure flowchart [22]

Appendix 18. Procedure new product introduction projects

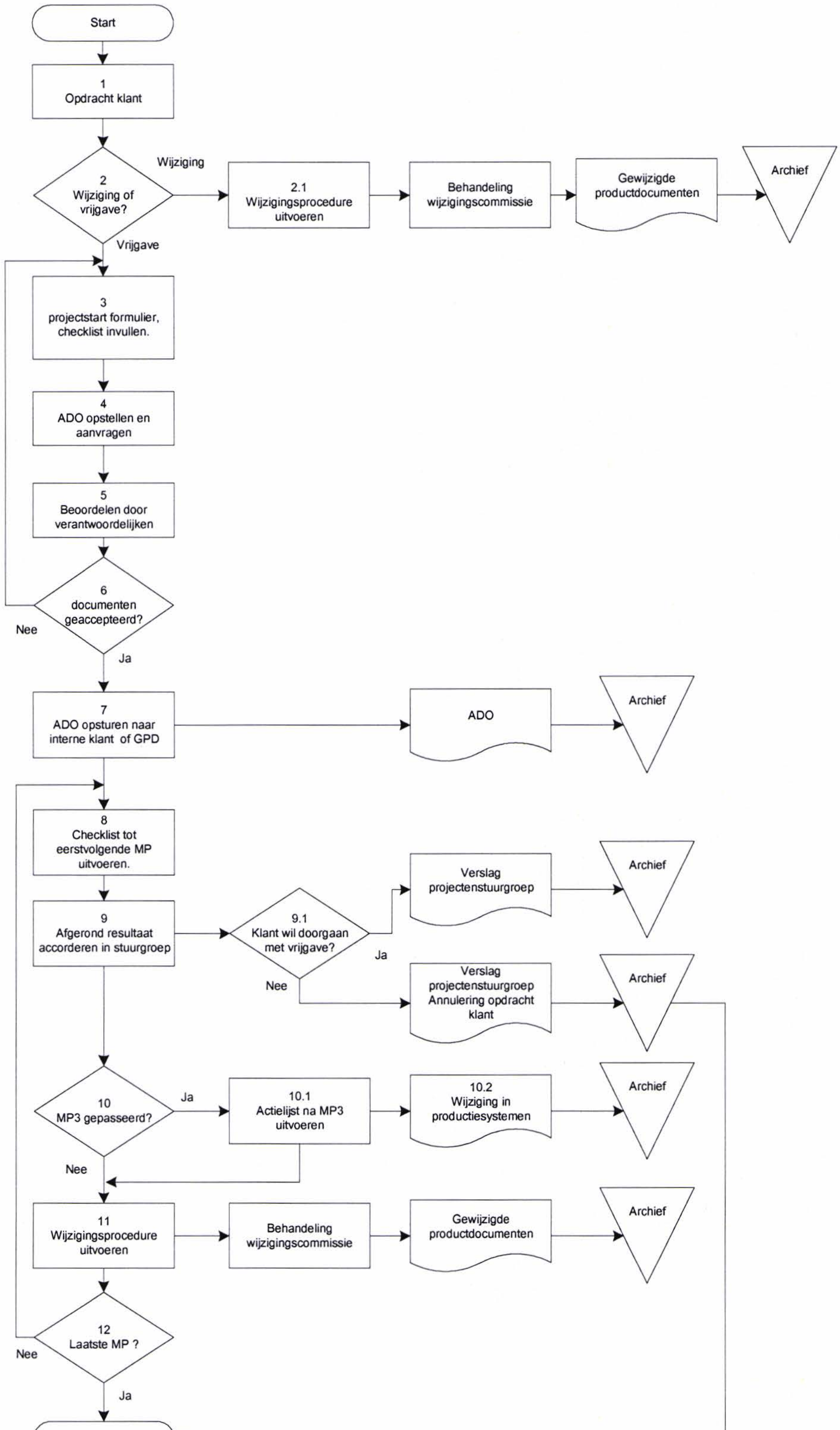


Figure A 18-1 Flowchart of the procedure for release projects [23]