MASTER

Warranty repairs
production planning and order acceptance

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Award date:
2008

Eindhoven, August 2008

Warranty repairs:

Production planning and Order acceptance

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BSc Industrial Engineering and Management Science — TU/e 2005
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in partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management and Logistics

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TUE. Department Technology Management.
Series Master Theses Operations Management and Logistics

ARW 2008 OML

Subject headings: production planning, warranty repairs, order acceptance

Preface

My Master Thesis project is finished. It has been a very educational experience, not only with respect to theory, but even more so with respect to the more practical side of such a large project. It, at times, has been very enjoyable and at other times, a little frustrating. Overall I look back at a well spent time period, which could have never turned out this way without the assistance, guidance and help of others.

First I would like to thank my supervisors at RICOLEC B.V. for letting me conduct this project at their company and supporting me during the project. I would like to thank Mr. Voorbergen for his comments, ideas and input in the project and his support during the day-to-day work. Mr. Hoornweg is also due thanks for his critical comments and suggestions. Lastly I would like to thank the repairmen for answering all questions and Mr. Kalff for providing with the as much of the necessary information as possible.

Secondly I owe thanks to my supervisors at the TU/e. My fist supervisor, Mr. Lambert, deserves credit for his support, ideas and comments both with regard to the content as well as the form of this report. Next to this I would like to thank my second supervisor, Mr. Flapper, for taking his time reading my reports and his valuable comments.

Lastly I would like to thank my family and friends for supporting me and listening to my, not always cheerful, monologues on the project. Special thanks in this regard are due to my girlfriend who deserves praise for her patience and the provision of the necessary distraction when it was most needed.

Summary

In recent years we have seen an increase in both the number of consumer electronic products per household and the diversity in these products and a decrease in the price of these products. On the other hand the responsibilities of producers for their products have been enlarged in most major economies as for instance the E.U. Together with lengthening periods of warranty coverage offered for marketing reasons this has led to increasing numbers of warranty claims and corresponding returns of products.

Companies differ in the manner they have chosen to handle this situation. Some companies, to avoid the large uncertainty with respect to returns, have outsourced the lucrative repair of expensive products and reimburse the purchasing price or a similar product for all cheaper products. However other companies, among which the company at which this case study was done, have chosen to keep the repair in their own hands. This leads to a complicated control situation of the returned products due to the diversity and unpredictability of the flow of products that might or might not be worthwhile to repair. On the other hand companies by doing this, beside the possible economic attractiveness, are enabled to get insight in the quality of their products and use the gathered knowledge in the development of new products and product support features and prevent fraud with the returns.

Each claim can be settled by multiple means, either by repairing the specific product, by distributing a new product or by reimbursing the submitter financially. However a claim has to be settled within a specific period, if not the only open option is to financially reimburse the claim.

This leaves the possibility to select the most lucrative part of the products for repair available to utilize the available capacity for repair, leaving other products unrepaired. However then nothing is known, with respect to quality, on the products not repaired. To obtain some knowledge these products can be tested. Also the repair of products is complicated due to the necessity of spare parts for repairs which might not be available. To obtain these parts cannibalization of other products can be applied.

Processing the stream of warranty claims therefore requires more then just the decision what to repair. In this report we have looked at all decisions in the process, being whether to repair a product, whether to test it, whether to cannibalize it and whether to settle the claim by replacement of the product or financial reimbursement. The decisions were looked at in different detail.

For the decision whether to repair four different redesigns were made focusing on the questions how to select the right products for repair and the right amount of products. Analysis revealed the type of failures, capacity utilization and throughput times for repair. These results and information available on the returns from a pre-sale test on a product type were taken as a base for the redesigns. The dilemma with respect to production control consisted of achieving high utilization rates without repairing products too late.

First the present production control system was formalized and extensions were considered with respect to order acceptance and stock keeping. The order acceptance undertaken when products arrive, thus the determination what to repair, was linked explicitly to the capacity available to repair products by means of the Work In Process. This redesign was extended with priority rules in which some customers receive priority depending on the number of days available for their repair. This based on differences in the maximum throughput time allowed for the different submitters.

This link was extended with a hard upper boundary in the second redesign, in line with CONWIP production control theory (Hopp and Spearman, 2000).

The third redesign modifies the order acceptance function into a two phase decision system with little costs for the second final decision on what to repair which is taken when a repairman takes the product. In this system the first decision to repair is, when workload exceeds a limit, reevaluated to come to a final decision to repair or not.

Finally the fourth redesign considers individual product stock keeping instead of the batches used in the first redesigns. This redesign was not fully developed, but only conceptually discussed.

The first three redesigns were compared by means of simulation varying among others the number of returns, their value and the number of days allowed for processing. The fourth redesign was compared to the other redesigns based on achievable upper limits.

Results indicate that under current constraints all redesigns can lead to close to optimal performance; because constraints with respect to the maximum throughput times are not stringent, the dilemma can therefore easily be solved by stocking products in the Work In Process. Decreasing the maximum throughput time for products, both redesign 2 and 3 outperform redesign 1, both with and without priority rules, because these redesigns prevent products from being repaired too late. The priority rule does improve results for redesign 1 compared to the situation without priority rules, however the results attained by redesign 2 and 3 are still higher in these situations. Under the considered practical relevant circumstances no significant difference was observed between redesign 2 and 3. However, considering extreme variations on both the supply and demand side redesign 3 is expected to be more robust against those changes. This is also evident in simulations with one day maximum throughput time, in which redesign 3 outperforms redesign 2. The performance of redesign 3 in terms of the maximal attainable value declines slightly with decreasing capacity but remains above 89% of the upper limit on the attainable value. Because of the high performance of this, and the other redesigns, and the necessary handling of products, it is concluded that stock keeping of products individually and an associated picking of products as proposed in redesign 4 is not expected to lead to large increases in performance.

With respect to literature these results indicate that extending the order acceptance decision into a two phase decision procedures with little to no cost for the second decision will only lead to better results when capacity is highly utilized and throughput times are stringent. This is in line with conclusions drawn on other extensions of the order acceptance function (Ten Kate, 1994) (Wester *et al*, 1992). Also the possible use of a maximum inventory level for the Work In Process in situations with varying product value is shown to yield better results than the same policy without a maximum inventory level. However in order to back and generalize these conclusions the impact of a hard upper boundary for the Work In Process on performance first needs to be tested under different arrival distributions and different cost functions for late repairs as well as different costs, in time and money, for the second decision.

With respect to the decision whether to test a product when it is not repaired a procedure was developed to obtain insight in the failure behavior of not to be repaired products. The procedure determines the correct number of tests on not repaired products for a given precision interval and confidence level. It is shown that this number, when confidence levels of 85% and a precision intervals widths of 0,20 are used, will be around 20 to 30 products. To achieve fast results the first arriving products should be tested. However this limits the statistical value of the tests due to the bias that might be present in this not random sample of the total returns.

Cannibalization is used extensively by RICOLEC. However an extensive policy to determine which products should be cannibalized is not developed. This because the requirements with respect to data are large and costly to gather, whilst the revenues of a comprehensive system are small since investments in spare parts is small. It is therefore not economically attractive for RICOLEC to develop such a system. A very simple rule governing the decision whether to stock a product for cannibalization was developed. This rule can serve as a simple heuristic to decide which products to stock for cannibalization.

Finally for the decision whether to replace a product or reimburse the submitter financially a simple heuristic was developed based on the costs for replacement and reimbursement. However this heuristic does not take into account the preferences of submitters, nor the physical possibility to replace a product, both of which are leading in the final decision and will therefore not be of practical use to RICOLEC.

Table of Contents

1. Introduction

The topic of this project is the processing of warranty returns at a trading company in consumer electronics. Here we will shortly address the developments with respect to warranty returns in this specific industry and the different ways of handling these returns in the industry. After this we will give a description of the company at which this project was carried out. Lastly we will discuss the structure of the report.

1.1. Warranty returns in the consumer electronics industry

1.1.1. Warranty: Increasing numbers

Traditionally consumer electronics are accompanied with a warranty with which producers take responsibility for the functioning of the product in the first years after purchase. During more recent years the warranty period also has become a marketing instrument in that warranty periods are lengthened to persuade customers into buying a product. Also governments, for instance the European Union, have accepted legislation which places more responsibility for the functioning of a product on the producer/importer (eg. EU (2002)). Warranty on consumer electronics generally demands the producer to supply the consumer with a new functioning product or give him his money back.

On the other hand, in the last decades the number of electronic devices per consumer has risen steeply (Widmer *et al*, 2005). Numerous new products and product types have been developed at increasing speed and others have become more affordable due to advances in technology. These developments have also made consumer electronic devices more complex incorporating more and more functionality in one product (Brombacher *et al*, 2005).

These developments have given rise to a large increase in the number of products governed by warranty in the field and, although it is widely assumed that the reliability of products has increased over the years, to a large number of warranty claims filed.

1.1.2. Warranty return repair: decreasing profitability, increasing complexity

In the past, consumer electronics could be regarded like capital goods in industry, highly valuable, and were repaired if physically possible. However the repair of consumer electronics is not that obvious anymore. The increase in complexity of products and the diversification of products has made it harder to find the failure in a product, since the number of possible failures has increased, and correct it. The decrease in price has made the repair less profitable. Besides this the increasing speed with which new product types are developed and the relatively small, and unpredictable, number of returns per product type, which mostly require slightly different repairs, have increased the skill needed for the repair of products and consequently the labor costs.

On the other hand the increase in complexity has made it more difficult for users to use a product. This has led to an increase in warranty claims for products that are not actually defect, but the consumer does not know how to use the product.

1.1.3. Warranty returns: reverse logistics

The developments discussed above have created a large flow of consumer electronic devices back to producers, a flow of which the size and composition is largely unknown and hard to predict. This flow is handled differently by different producers. Some producers have at the moment chosen to outsource the repair of the products still economically profitable to repair to specialized repair companies and to reimburse the purchasing price for other products. This option saves companies from the duties of performing repairs and all the uncertainty related to the flow of returns. On the other hands it also makes it more difficult to prevent fraud in repairs, filter out easily repairable products, consumer faults and it complicates the analysis of the quality of products based on the received warranty returns.

Other companies, as the company at which this project is done, have chosen to repair products themselves in order to have control over their products and their claims. However this choice requires these companies to process these products and it obliges them to choose which products are repaired and for which either a replacement or a financial reimbursement needs to be made.

1.2. Company description

The used brand names are made-up and mask the real brand names.

The company at which this project was conducted, RICOLEC B.V., is now a trading company employing 25 people. However the company started as a retail shop in music records and electronics, which formed the foundation of what the company has become today. Over the years, RICOLEC has evolved from a retail business to wholesaler and on to an import company in the electronic consumer goods branch with a growing turnover that measured around €20 million in 2006.

From the 70's onwards RICOLEC has imported electronic consumer goods from Japan, Korea, Taiwan and China. Over time the sold product assortment has evolved into a large product and brand portfolio, with brands that stand strongly in the market, and are being sold through well-known channels. Next to the sale of other brands through RICOLEC BV, the company represents the following brand names on an exclusive basis:

- CED
- CEA
- CEB
- CEC
- CEE (part of the assortment)

The product portfolio of RICOLEC today includes a wide range of products in various segments and prices, including LCD-televisions, car-audio, micro-systems, DVD-players, portable DVD-players with LCD-screen, telephones and clock radios among others. Under the CEE brand, RICOLEC sells Digital Enhanced Cordless Telecommunications (DECT) telephones, which is a partially digital alternative for traditional cordless telephone handsets. These products are sold via the usual end-user distribution channels for the industry, being shops, department stores and internet-shops.

RICOLEC B.V. not only sells the products, but is also responsible for the quality and after sales service of the products. Therefore all products returned by end-users and other parties in the Benelux are the responsibility of RICOLEC. The products send back because of perceived defects need to be examined and the source needs to be compensated by either a working product or reimbursement, the costs associated with this for the sender of the product and RICOLEC are dependent on the warrantees accompanying the product. All the returned products, around 20000 products of over 150 product types yearly, with the exception of DECT phones, are processed by RICOLEC. To be able to do so RICOLEC employs 4 repairmen and 2 administrative employees.

1.3. Report structure

This report is structured as follows. In chapter 2 the problem is formulated based on a process description and the solution methodology is explained. Also the relation to the academic literature is shortly discussed. Chapter 3 discusses the relevant literature for this project. In chapter 4 an analysis of the current state of affairs is given. Chapters 5 to 11 discuss the constructed redesigns for different parts of the process. Chapter 12 then discusses the settings for a simulation of various redesigns. The results of this simulation, complemented with other insights are discussed in chapter 13 to 16. Finally, chapter 17 gives handles the resulting recommendations for RICOLEC and chapter 18 discuss the contribution to academic literature.

2. Research & problem definition

RICOLEC is not satisfied with the current way returns are processed and feels that the decision rules governing the process can be improved. The motives of RICOLEC to modify the process are discussed in the first section. Then we will specify the approach followed in this report to solve the problems perceived by RICOLEC. Thirdly we will discuss the return process. After this the situation is structured by means of a preliminary analysis of the processing options for the returns, the corresponding decision points and controls regulating the decisions. With the help of the results of this analysis we will define the problem more specifically and specify several research questions. Lastly we will place this research in the context of the academic world and we will discuss its relation to literature.

2.1. The problem as perceived by RICOLEC

RICOLEC has three motives to change the current situation. The first is that the current situation is unable to provide insight into the failure behavior of a lot of products. This because a lot of products, around 10000 products yearly, when submitted under warranty, are not examined because they are not repaired. This insight is desired by RICOLEC to confront the suppliers of bad-performing products and to be able to construct contracts with suppliers that include warranty cost sharing.

The second motive is the fact that RICOLEC has no structured insight in the profitability of repair or stocking for cannibalization for the different products and therefore does not know whether they are using the available capacity and inventory in an optimal way. In other words they do not know whether they are repairing the right products and whether they are doing this in the right way.

A third motive, related to the second motive, is that in the current situation the throughput time of the submitted products is not explicitly controlled and there is no insight in the throughput time distribution of products considered for repair. This insight is important since more and more customers demand their products to be repaired within a specified time period. If a product is not repaired within the period RICOLEC is obliged to reimburse the submitter financially.

2.2. The research framework

The research is conducted according to the logic of the regulative cycle, displayed in figure 2.1. The cycle passes through the phases: problem definition, analysis and diagnosis, plan of action, intervention and evaluation (Van Aken *et al.* 2007). The problem definition is distillated out of the problem mess, which describes the current affairs at an organization. The problem definition drives the project, but can also be dynamic since further research can alter the understanding of the situation. This project takes the design perspective and tries to solve the problem by designing a solution. Van Aken *et al.* (2007) developed a general model for a design process, which is followed during this project. The model distinguishes multiple steps that lead to a design: problem analysis, developing specifications, sketching, outline design and detailing. These steps are performed in a sequential manner and controlled by process management within the project. The model is depicted in figure 2.2.

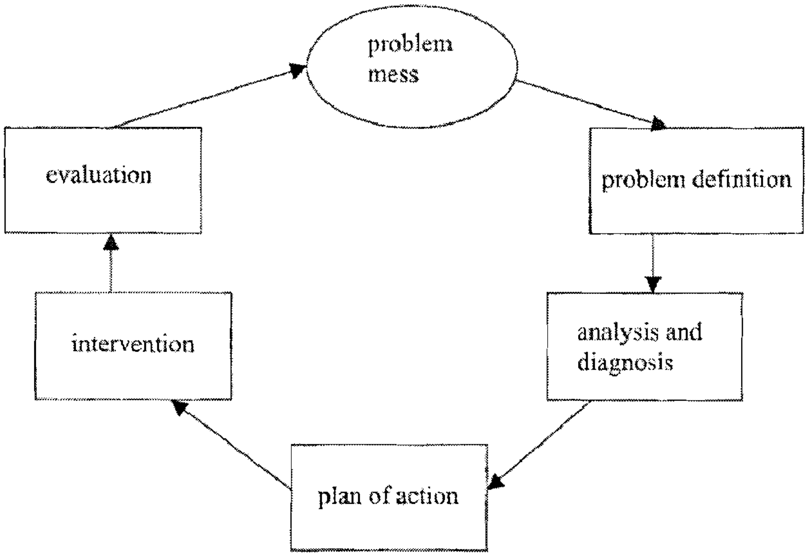

Fig. 2.1. The regulative cycle (Van Aken *et al*, 2007)

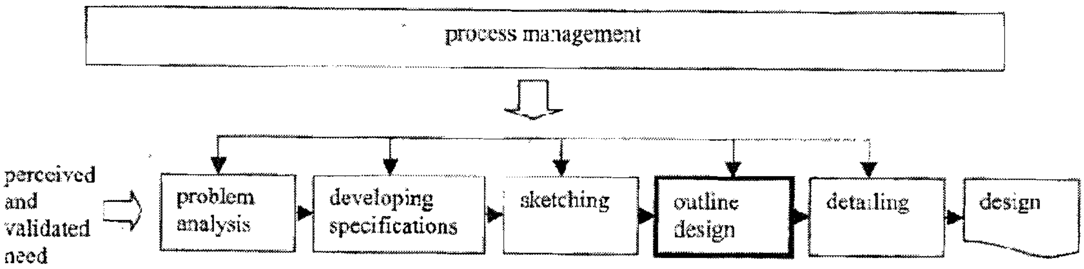

Fig. 2.2: A general model for the design process (Van Aken *et al*, 2007)

2.3. Preliminary analysis: The return process described

Annually RICOLEC receives over 20000 returns. All these returns are processed by RICOLEC following the same procedure. The one exception on the above scenario is the processing of DECT telephones. These returns, when due to warranty, are always reimbursed and the phones are sent back to the factory. RICOLEC is then reimbursed by the supplier.

In the process three different parts can be discerned. The first includes the take-in and administrative booking-in of the product. This ends with the decision whether a product is within or out of warranty and the decision whether a product should be repaired or not. The other two parts are dependent on whether the product is within warranty or out of warranty. If the product is to be repaired and within warranty it enters the repair process. If a product is out of warranty it is also processed by the repairmen. If the product is not to be repaired and within warranty the product at the moment is not further processed but simply either sold secondhand or put in stock for cannibalization. Testing on not repaired products is currently not undertaken. Below we will discuss the different parts in detail.

2.3.1. The take-in process

Everyday returns arrive at RICOLEC. These returns are handled by the return-department which consists of one full-time and one part-time employee. The returns are delivered by different logistic service providers and arrive in batches. It is unknown beforehand how many returns will arrive on a day. Each return should be accompanied by a description of the product failure, the receipt of purchase and the proof of warranty. Each batch is also accompanied by a list which states the contents of the batch. The employees check the content list and the individual return documentation on availability and correctness. To do so they have to take the return out of the batch. After this the information on the return is entered into the administrative system. This includes:

- Customer information of the submitting company/person: name, address etc.

- Product information: date of purchase, date of arrival at RICOLEC, the brand, product type, product group, information on accompanying accessories, information on the physical state of the product e.g. when a product is damaged and information on the inclusion of purchasing and warranty receipts;
- Complaint/problem information: a textual description of the problem perceived by the user.

This information is then printed and attached to the submitted product.

Based on this information the decision is taken whether a product is covered by warranty and whether to repair a product or not. The coverage by warranty is decided upon based on the warrantee conditions and the time in use. The decision criteria used for the decision to repair are based on the product type and error type observed. The products that need to be repaired are put in carts. When a cart is full or at the end of the day, a tag is attached to the cart stating the arrival date of the contents of the cart; all products in one cart have the same arrival date and the cart is moved to the repair department inventory. The carts are used to save on transport time to and from the inventory and to keep the stock organized. The returns that are within warrantee and are not repaired are collected on a pallet or put apart for the spare parts stock. If the pallet is full it is transported to the secondhand inventory. The warranty claim accompanying a product is settled by financial reimbursement or a replacement product when a product is not repaired. This decision is taken directly. Products that are not covered within warranty are sent to the repair department for examination.

2.3.2. The repair process for warranty returns

The carts with products to be repaired are stored in the inventory. A cart is taken by the repairmen to their workshop and their all jobs in the cart are handled after which the processed products are transported to the processed returns inventory, again in carts. The products are repaired according to arrival date with on a first come first served basis. However some, unclear, priority is in place for more important customers. The repair department is staffed by 4 employees. Two fulltime employees and one part-time employee fully dedicated to the repair of products and one fulltime employee that repairs products but is also in charge of the product support via the website and telephone and therefore only has limited time to repair products. Some specialization is in place; however this is very flexible and not transparent.

The repair of a product consists of several distinct steps. First a repairman takes a product out of the cart and places it on his desk. Then the product is taken out of its package. After this the repairman looks up the repair in the system with the help of the attached information. Then the physical repair takes place. The repair can be successful or unsuccessful. If the repair is successful the repairman enters the corresponding IRIS-codes indicating the location of the failure, the defect type and the repair action taken and a textual description stating the actions taken into the administrative system and the repair report is printed. Then the product is packed in such a way that it can be send back and placed in the outgoing cart. Lastly the repair report is attached to the repaired product. The use of parts is not registered. If a product is cannibalized to obtain parts this is usually done during the repair of the product to be repaired or at times when little work is in stock.

If a repair is unsuccessful the product is replaced or the customer is reimbursed along the same criteria used for not to be repaired products. The left over product is either stocked for cannibalization if it contains usable parts which are low in stock, or reserved for secondhand sale. The replacement of the product is entered into the administrative system and the repair report is printed, the outgoing product is packed and placed in the cart and the repair report is attached to the product.

2.3.3. The process for returns out of warranty

All received products that are not covered within warranty are further processed by the repair department. When a product out of warranty arrives it is inspected to determine the possibility and costs of repair. Then a proposal stating the costs of repair or the costs of replacement is made. This proposal is given to the submitter of the product. If a submitter accepts the proposal the product is either repaired or a new product is distributed along the same route as a within warranty repair travels. Repairs are assumed to be always successful with out of warranty returns, this because only when a repairman is very sure he can successfully repair the product a proposal for repair is made. If a submitter declines the proposal the product is sent back to the product owner since it is their property.

2.4. Preliminary analysis: decision options

In the previous paragraph the process which processes the returns is described. Here we will look at the options available in this process for a submitted product, either covered in warranty or not.

Incoming products are accompanied with a warranty claim or are out of warranty returns. Therefore we can discern two entities: the submitted product and the submitted claim. These entities can be processed together or separately. If a product is not covered under warranty only the product remains. The product is then repaired for a fee. Here we will first define the options open to RICOLEC to settle an incoming warranty claim. After this the processing options for the failed product accompanying the claim and other submitted products will be defined. Thirdly we will discuss the constraints faced by RICOLEC in this process. Lastly we will discuss the decision points and the rules currently governing the decisions. We again notice that for the testing of products not considered for repair no procedures are in place. At the moment this is simply not done and therefore no analysis concerning the testing of products can be made.

2.4.1. Warranty claim settlement options

A warranty claim originates at the end-user who has experienced a problem with his product and is entitled, because of warrantees, to a functioning product. The claim is always accompanied with the defect product. For all the justified claims, the warranty can be fulfilled in three ways:

1. By repair of the submitted product and redistribution of the repaired product
2. By redistribution of a new product to the customer
3. By disbursing the money for the product to the customer

The cost associated with all options is borne by RICOLEC B.V. If a claim is not justified under the guarantees applicable to the product no obligations exist towards the customer.

2.4.2. Product processing options

The possible courses of actions for each returned product accompanying a claim are multiple. For each product five processing options are possible:

1. Repair the product with the aim to send it back into the field either to its owner or to a selling point. The repair is performed on the submitted product. It is not acceptable to send a different repaired product of the same type to the submitter.
2. Disassemble the product to obtain spare parts which can be used in the repair of similar products
3. Sale of the product to a second-hand broker who sells the product in foreign markets
4. Restocking of the product with the intention of making a new sale
5. The received product can be send to the supplier of the product to RICOLEC

The last two options are not expected to happen regularly. Next to that the options only apply to very specific products. With regard to the fourth option, it is only possible to restock for a new sale if a product is in perfect condition and not technically outdated, which will rarely be the case for a warranty return. The fifth option is applicable to product series with chronic faults. RICOLEC can send these products back and claim financial reimbursement. This happens only rarely and needs to be seen as a high-level management decision. Besides as stated, RICOLEC does not have mechanisms in place to detect these faults easily. Because of these peculiarities we will not focus on these courses of action in the determination of the optimal course of action for a specific product. If a warranty claim is not justified the defect product is send back to the customer. The costs made by receiving these products and sending them back as well as the capacity of the collection department needed are neglected in this report.

We should also distinguish *returns out of warranty*. The repair of these returns, when repaired, is paid by the consumer. These repairs, when undertaken, are always successful.

2.4.3. Process constraints

The process has a few constraints posed by the customers, the suppliers and the system of RICOLEC. These are listed here.

Most customers oblige RICOLEC to settle the warranty claim within 10 working days. Some companies, responsible for the majority of the returns demand a refund when the claim is not settled within 10 days. This refund equals the price RICOLEC needs to pay when it does not repair a product. Therefore RICOLEC aims for a throughput time of the process of 10 working days. It is expected that this figure needs to be lowered in the future.

RICOLEC has a storage facility for spare parts. This facility is used to store both new spare parts and products to be cannibalized; the precise capacity is unknown and not taken into account in the project. The storage facility which stores secondhand products has ample capacity.

RICOLEC does not actively keep track of its stock of newly bought parts and to be cannibalized products stock. No use is made of stockkeeping costs and the obsolescence risk of the spare parts is not explicitly taken into account when ordering new spare parts. RICOLEC also gets some spare parts for free from their suppliers, however the type and amount of parts is not under the control of RICOLEC.

RICOLEC faces a limited capacity for repair. Two fulltime repairmen and two parttime repairmen cannot repair all submitted products. RICOLEC does not see opportunities to extend capacity temporarily in view of high workload because repair is highly specialized task which cannot be performed by temporarily hired workers without thorough on the job learning. RICOLEC expects that in the long term no workers will be hired or fired, the present capacity is therefore considered fixed at the current level.

Repair is not a perfect action. The outcome of the repair process is insecure; a product might not be repairable. This becomes clear during the repair process.

2.4.4. Decision points and rules

In the return process multiple decisions need to be made with respect to the claim and the submitted product. Figure 2.3 on the following page gives a claim and product flow diagram indicating the decision points, their order and structure. This diagram is only applicable to justified warranty claims.

The model displays the flow of a claim and product through the process using an adaptation of the Petri-net modeling language (Jensen and Rozenberg, 1991). This language is highly appropriate to display the structure of processes. In the process depicted in the flow diagram three decision points can be discerned. The first is the decision whether to repair or not, this decision is taken for the claim and the product together. This decision is taken when the product is accepted as being covered under warranty. If a product is not repaired, or when repair fails, the processing of the claim and the product need to be done individually. Therefore, if this is the case, two more decisions need to be taken. The first decision is how to settle the claim, either by replacing the failed product for a new one or by reimbursing the customer his money. The second decision deals with the product, should the submitted product be resold to a secondhand salesman or should it be cannibalized for useful spare parts. These two decisions are independent and always a consequence of the first decision and the repair process.

The decisions currently taken in the return process are governed by rules indicating when which option is chosen. The decision rules in use are:

- **Repair or not?:** The decision is based on product type, eg. a certain model of television. In general the products with the higher sales prices are repaired. However products that are reported as death on arrival (DOA), which means that they have never functioned and did not function from the first attempt of use, are never repaired.
- **Replace or reimburse?**: Generally reimbursement is the used option. Only if the submitter has specifically stated he wants a replacement product one is given. If a product is not complete when submitted (eg. a audio set is submitted without speakers) the submitted part of the product is replaced when possible. Else the claim is reimbursed upon receipt of the remaining parts of the product. If a repair fails the decision is taken based on the same criteria.
- **Stock or sell?**: Products that are not repaired are sold. However DOA products of product types that are normally repaired are stocked for parts if the repairmen consider a larger inventory of spare parts necessary. Products that are repaired but the repair failed are also considered for cannibalization. In this case the decision whether more stock is necessary is taken by the repairman based on his opinion.

As can be seen, no rules are in place for the testing of products that are not considered for repair, therefore this decision is also not incorporated in figure 2.3.

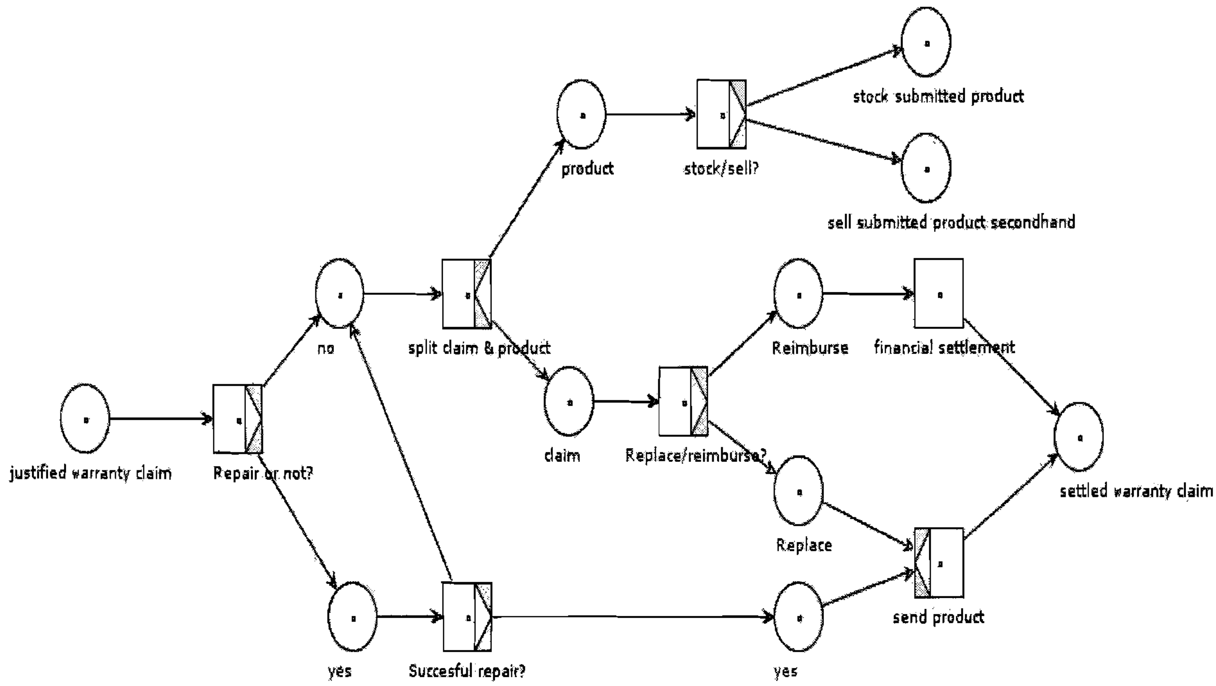

Fig. 2.3: Warranty return/product flow model

2.5. Detailed problem description & research questions

Now the possible courses of action for returned products and claimes are defined we can specify the problem in more detail than the motives discussed in paragraph 2.1. Here we will first formulate the problem in more detail and examine the costs and revenues associated with the different courses of action. We will conclude with the research questions coming forth out of the problem.

2.5.1. Processing options: costs and benefits

The challenge in this project is to redesign a set of decision rules that improve the performance of the warranty return process, i.e. in terms of the realized reimbursement value of repaired products, on the one hand and to obtain more insights in the failure behavior of not repaired returned products. In other words the decision what to do with a submitted claim and product should be extended to include testing and improved.

The best warranty and product processing option for each product is determined by the costs and revenues associated with the first three possible options for processing of the product and the cost and revenues of the options for settlement of the warranty claim for each claim. The costs of settling a warranty claim are either the costs of repair and redistribution of the product in case of repair, the price of the replacement product and its distribution costs in case of replacement or the sales price of the original product in case of financial reimbursement. In case of unsuccessful repair the cost are the costs of repair plus either the costs of replacement or reimbursement. The administration costs associated with the processing of products are not considered, since they have to be made for all products and do not differ between products. Therefore it is assumed they do not influence the optimal course of action for a product.

The costs of the product processing options are based on multiple cost drivers. The cost components that can be discerned for each of the three product processing options are listed below. The costs of repair are determined by three components:

- The time needed by a repairman for repair of the product. This time is dependent on:
    - The type of product

    - Type of error
    - Product specific circumstances
- Costs of spare parts. These costs are dependent on:
    - The type of product
    - The type of error
    - Supply situation (in stock/cannibalization)
- Overhead costs (building, equipment, etc.)

The costs of cannibalization of a product are dependent on:

- The time needed by a repairman for cannibalization of the product. This time is dependent on:
    - The type of product
    - Type of part
    - Product specific circumstances
- Costs of disposal of the remainder of the product. These costs depend on:
    - The type of product
- Overhead costs (building, equipment, etc.)

Only overhead costs are associated with the third option of the sale of the products to a foreign market reseller. The revenues of this option consist of the price paid by the secondhand salesman.

The possible warranty settlement and product processing combinations and the associated costs and revenues are shown schematically in figure 2.4. The overhead costs are left out of the picture, because they can be considered as sunk costs, since they cannot be influenced in this project.

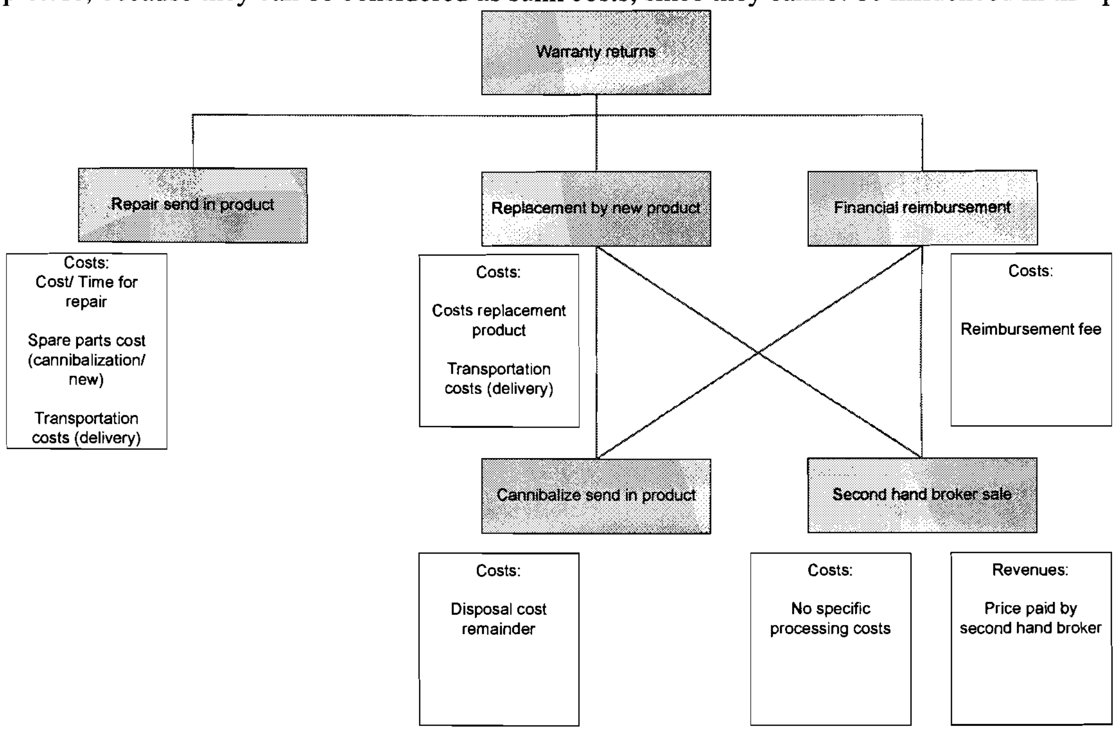

Fig. 2.4: Warranty settlement and product processing combinations cost structure

2.5.2. Research question(s)

Taking the motives of RICOLEC and the preliminary analysis of the process, the decision options and the associated costs into account we can formulate two main research questions for this project. The first is solely based on the first motive of RICOLEC since, as stated in the analysis, no testing of not repaired products is currently conducted.

How can RICOLEC obtain insight in the failure of its products in the field by testing products received in the warranty return flow?

The second research question incorporates the second and third motive of RICOLEC and addresses the performance of the return process as described in paragraph 2.3. The question focuses on the allocation of products received under warranty over the different options open to the product and the claim and aims to minimize the costs associated with processing the returns.

How should the submitted warranty claims and products flow be allocated to the different settlement/processing combinations in order to process the claims and products more cost-effectively?

To answer this question one has to take into account all the constraints that this process faces. If we translate this research question to the different decisions that need to be taken in the return process we can formulate questions that can be addressed per needed decision.

To repair or not?:
How to select the right amount of products for repair?
How to select the right type of products for repair?

Subject to constraints with respect to throughput time and the fixed and limited capacity of the repairmen.

Replace or reimburse?:
How to determine when a claim should be settled by replacement or reimbursement?

Cannibalize or sell?:
How to select the right type of product for cannibalization?
How to select the right amount of products for cannibalization?

Subject to constraints with respect to the fixed and limited capacity of the repairmen.

The questions, especially cannibalization and repair, are related due to the shared capacity of repairmen available for both actions.

2.6. Relationship to the academic literature

The decision whether to repair or not needs to be made for every claim. In literature this is termed order acceptance. In the models described in literature the accepting of an order has consequences. The order once accepted should be processed within the time allowed for its processing. This is regulated by the scheduling function that determines when which order is processed. The order acceptance and scheduling function are therefore related and often discussed together in literature.

However, the situation observed at RICOLEC where a repair is useless once it is not performed within the maximum throughput time causing a situation with immediate lost sales in case of late delivery on the one hand, but on the other hand the decision whether or not to repair can also be changed after it is first taken, is different from the models discussed in literature as we will show in chapter 3.

Therefore, the situation discussed here, in which after an order is initially accepted it can still be decided not to repair the order after all and where costs associated with late repair equal the cost of the other processing options available to RICOLEC, namely reimbursement costs, is relevant to study in view of the academic literature.

3. Literature study

From the problem definition a few areas of interest can be distilled. Here we will review the relevant literature on these areas in order to form a theoretical base upon which to focus in the analysis of the current situation and more specifically in the design of a solution to the stated problem.

A number op topics is discussed. First we will shortly discuss warranties. After this a brief review is given of the product failure related literature and the classification systems in the electronics industry. Thirdly warranty returns and their usefulness in improving product quality will be discussed. Fourthly we will discuss warranty return sampling. Fifthly we will focus on the repair department and discuss order acceptance, sequencing and throughput time regulation. The search method and terms used for this section can be found in Appendix 3. Sixthly, cannibalization and its uses and applications are treated. Finally a conclusion is given.

3.1. Warranties

When a justified warranty claim for a product is made by a customer a producer has the obligation to equip the customer with a functioning product or reimburse the customer financially. The producer generally has, besides financial reimbursement, two possibilities to satisfy this request, he can either repair the send in product or redistribute a new product to the customer (Murthy *et al*, 2004). However it depends on the warranties in place how this process is arranged specifically. Important variables in the warranty are (Murthy and Blischke, 2005):

- Dimensionality of the warranty: A warranty is based on a number of variables. Normally time is included, but use related variables like mileage can be included as well leading to a multidimensional warranty.
- Renewing or non-renewing warranty: If a warranty is renewing the warranty period is measured from the time of replacement. If a warranty is non-renewing it is measured from the time of first purchase
- Free replacement / Pro-rata / rebate warranty: A free replacement warranty supplies the customer with a replacement for free, while a pro-rata or rebate warranty obliges the supplier to supply either a (partial) monetary refund (rebate) or a replacement at discounted costs (pro-rata) to the customer.

With these variables numerous combinations can be made, leading to the many different types of warranty that exist. The options are further extended by options like exemption clauses, that exempt certain parts (partially) from warranty, and cumulative warranties that cover groups of items (Murthy and Blischke, 2005).

Another variable, not explicitly warranty related, although it might be defined in the warranty, is the type of product distributed to the customer. If a replacement is given, this can be a new product or a repaired product. A new product has a failure distribution similar to a new bought product. This is not certain for a repaired product. In literature two types of repair can be distinguished, both at one end of a spectrum. On the one end is repair leading to an as good as new product. On the other end is repair leading to a product just as good as the failed one, except without the failure. These products differ with respect to their failure rate. The first has the failure rate distribution of a new product, the second the distribution of a product already used for some time. The decision whether to replace or repair therefore is dependent on the quality of repair. For heuristics and optimal procedures determining time intervals for repair and replacement see Jack and Van der Duyn Schouten (2000), Jack and Murthy (2001) or Murthy (1996).

Besides the legal obligations present to satisfy justified warranty claims, a number of reasons can be present for a company to take back the products or parts of products on which the warranty is claimed. Flapper (2005) distinguishes ten reasons which vary from the prevention of fraud to the filing of claims at the company‘s suppliers.

3.2. Product failure & failure classification

3.2.1. Product failure

Every product can break down. The possibility of breakdown however is different for different products. In general, the variables determining the chance of failure include the quality of the product influenced by product specifications and production statistics, the time a product is in use and the way a user uses the product (Brombacher *et al*, 2005). However in the field the only easily observable characteristic is the time a product is in use. Neither the desires of the customer nor the statistical variation in a product due to production are readily available. Therefore we will focus on the failure behavior of products with respect to its lifetime.
The chance a product fails at a specific point in time is defined as the failure rate. Traditionally products were stated to have a high chance on failure early in their life followed by a low chance during their normal life and an increasing chance when old age was reached. The first high is caused by so called infant mortality, the second high chance by fatigue and wear-out. This results in the widely used bathtub curve shape indicating the chance a product fails, see eg. (Wang *et al*, 2002).

With regard to electronics research showed that several branches of electronics industry follow a curve known as the roller coaster curve (Lu *et al*, 2000). This curve is displayed in Figure 3.1.

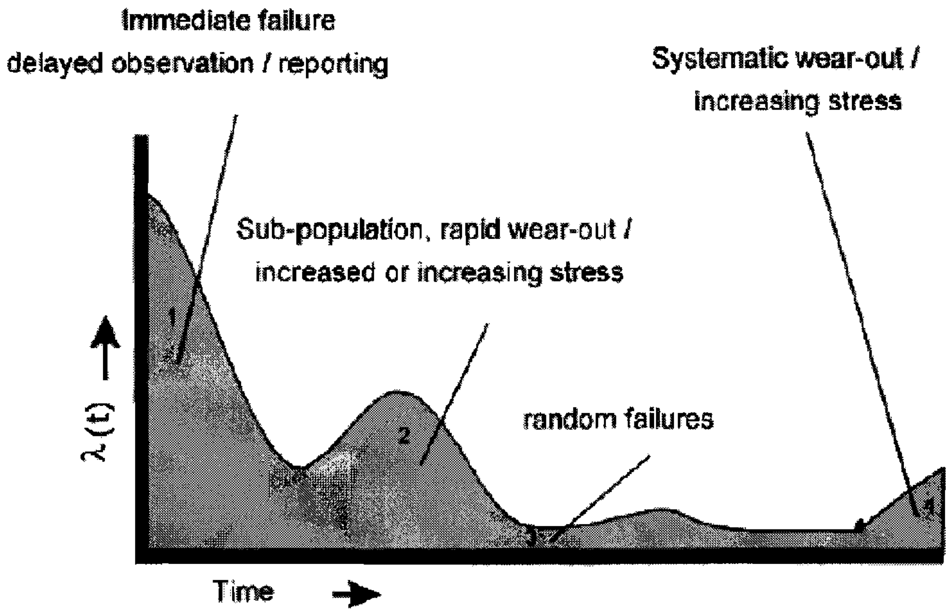

Fig 3.1 The roller coaster curve (Lu *et al*, 2000): Failure rate over time

Compared to the bathtub curve one phase is added, phase 2. This phase is caused by the combination of users that use the product extremely intensive, more intensive than anticipated, and weak products as a result of variation in production. This combination leads to rapid wear-out, however this only happens in a subpopulation of the total group (Lu *et al*, 2000). These failures are important for warranty, since they often occur within the warranty period.

3.3. Warranty returns, product quality & failure

3.3.1. Field feedback & product quality

Product quality is determined by a variety of factors. Next to product design, user expectations and material quality among others play a role. For manufacturers to improve on their quality levels the weaknesses in current product user combinations need to be known. Different sources are available in the field for this information (Petkova, 2003). One of these sources is comprised of the failed products send return.

Petkova (2003) distinguishes two types of information, engineering information and statistical information. The former includes the information necessary to find the cause of a problem, thus is vital for product quality improvement. The latter includes the frequency of returns and further statistical information involving product returns. This information is useless for product quality improvement without engineering information, however in combination with engineering information it gives a detailed image of the quality of a population of products and can greatly help to identify the most profitable quality improvements.

Petkova (2003) concludes that field feedback is usually too late to facilitate quality improvement of products and that it is hardly possible to improve this because of the time delays inherent in the matter. Nonetheless engineering information can be of use in the design of subsequent product types, especially if standard designs are used as is the case in the mass-production consumer electronics industry (Petkova, 2003).

An example of a classification method for engineering information is the IRIS code used by the majority of service centers in the brown and white goods. Petkova (2003) states that the IRIS code information is not useful to find the underlying cause of a reliability problem. This because it is not detailed enough, because it only describes the symptom and its diagnosis, and because the interaction between the product and its surroundings is not considered. Lastly she states that the indicated location of the failure has not necessarily caused the problem. Nonetheless the system has its advantages in its ease of use and its wide applicability and usage. Besides, the system does assist in finding the final failure mechanism on a part or module level which can serve as a starting point for further examination by the manufacturer. Also the argument of not considering the interaction between the product and its surroundings becomes irrelevant when multiple products are examined per product type since probabilities that failure comes from extreme usage for all returns is very small and can be defined as bad product design. Therefore we will give an explanation of its origin, basis and functioning.

3.3.2. The IRIS classification

In the mid ‘80s SONY was the first electronics manufacturer that made factories responsible for the quality of their products and therefore also must bear the warranty costs of those repairs. This resulted in a need for information on the performance of products on the market. This need was fulfilled by after-sale service organizations. However the communication between service/repair organizations and the producers was faced by difficulties like geographical differences, language and the fact that most repair was done by external companies (authorised servicers and dealers). Therefore a standardized Repair Description Language was developed by SONY (IRIS_course, presentation of EICTA).

This language now serves as the basis for the International Repair Information System, abbreviated IRIS. This language is used in Europe and Japan for the coding of failures and repairs of brown goods. An effect of the standardization is the codes presence in most repair administration software (IRIS_course, presentation of EICTA).

The IRIS code consists of 6 different parts and codes the symptoms, diagnosis, defect and repair. Next to that it indicates the type and number of spare parts used during the repair. An example of an IRIS coding strip is shown in figure 3.2, with this figure we will explain the different parts of the code.

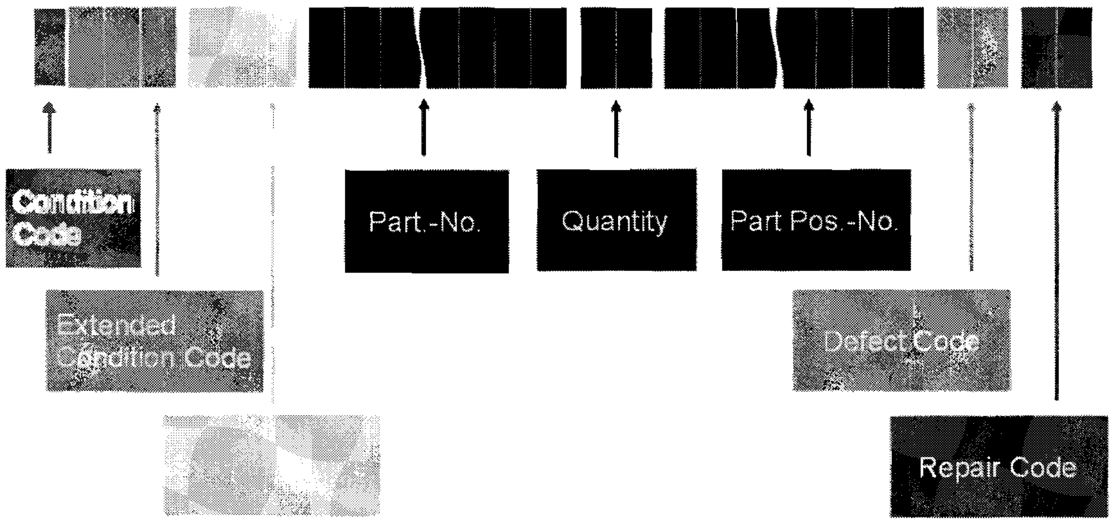

Fig. 3.2: An IRIS classification strip (How Iris Works, presentation of the EICTA)

The parts are represented by the different colors used in the figure (IRIS_course, presentation of EICTA) :

- Condition code: This part is filled in by the customer and describes the conditions under which the failure takes place. When it is hot or humid. Conditions should be noticeable by a "ordinary" customer
- Extended condition code: The condition code can be extended to include at which part of the machine and during which functional performance the defect is observed. For instance watching DVD's the lower left corner does not work. This is done by a customer
- Symptom code: Here the symptoms of the defect are described by the customer. For instance no sound, or no vision. In some countries two symptom codes are entered, next to the customer, a technician also describes the symptoms here
- Part number, quantity and position: This is manufacturer dependent and gives the precise location, number and type of parts malfunctioning and repaired/replaced. Sometimes even the place on the part (for module structures, or printed circuit boards for instance) can be indicated
- Defect code: Here the technician specifies the defect he has found. This can relate to the malfunctioning part. However the defect can also be of a software nature or no defect can be found at all
- Repair code: The technician indicates what he has done to fix the defect. If the defect was fixed he adds a flag. It can be that he performs multiple repairs for one defect, then the one that fixed the problem is flagged. Also repair codes like software upgrading or return without repair are possible here.

All input on the sheet is coded to prevent language problems. For every type of machine codes exist that correspond with the type of condition, symptoms, defects and repair possibilities. The tables with these codes and corresponding meaning are available in all European languages; an example of a table used at RICOLEC is displayed in Appendix 3.2.

The advantages of IRIS accrue to all parties involved. The servicer/repair company can handle their repairs more professionally, accurately and faster because of the structured data input. The manufacturer gets structured, insightful data on problems and therefore can address these problems more easily in new generations of products (IRIS_course presentation of EICTA).

3.4. IRIS-classification warranty sampling

Since testing all products is very time consuming, we will shortly address the option of sampling to obtain information on the failure of products. IRIS-codes only classify a failure. They do not give a hierarchy. Therefore one cannot speak of a mean IRIS-code. However, some failures occur more frequently than others, and this information is of interest in countering failures, as expressed in the previous section. A way to obtain information on the frequencies of occurrence is by sampling and registering the obtained IRIS-codes.

The sampling of nominal data is based on the representativeness of elements in a population for that population. A good sample is accurate, which means unbiased, and precise, which means that the error in the sample is sufficiently large to draw conclusions. Since a sample relies on part of the population it is never completely sure the resulting estimate is the true value, the precision determines the interval for the estimate and the degree of confidence one can have that the real value is in the interval (Cooper and Schindler, 2003).

For each return there is a chance that it has a certain IRIS-code and a chance it has not. For each possible IRIS-code this is true. Then we could test whether a sample is coming from a certain distribution by calculating:

$$z_0 = \frac{x - n \times p_0}{\sqrt{n \times p_0 \times (1 - p_0)}}$$

In which:
z_0 = standard normal distribution value of the sample for the IRIS-code
x = number of occurrences of the IRIS-code
n = total sample size for a product
p_0 = known probability of occurrence of the IRIS-code
(Di Bucchianico, 2000)

Then comparing z_0 to the value for standard normal distribution value of a certain percentage we can state whether the probability in the sample is larger or smaller then p_0 with a certain degree of confidence.

The problem is that oftentimes the probability an event occurs is unknown beforehand. It can be estimated from the sample. However with the above formula we can calculate, with a predefined confidence level, an upper and lower boundary on the probability of occurrence. The real value will then be in this range with the predefined level of confidence. We can then calculate this range after every draw and stop drawing products when the desired range is reached.

3.5 Order acceptance & scheduling

Although reverse logistics flows, as to a repair shop, are characterized by large uncertainty (Thierry *et al*, 1995), still the control of production can be viewed at a similar manner as in forward flows. The uncertainty does increase the value of information on orders and products as is discussed by Ketzenberg *et al* (2006). This information can then be used to control production.

To control production, to make sure the right products are repaired on time, in a make-to-order situation two controls are available. The first regulates the amount of work in a system. The second determines the order in which products are processed. The first is called order acceptance function. The second is called the scheduling function. In general the first is executed before the second (Bertrand *et al*, 1998), this since order acceptance determines which orders are processed whilst scheduling the determines the order and resources with which this is done. However the two are related since one forms the input for the second. In literature the topics are discussed jointly and separately. We will first discuss both functions separately, since in practice they are often separated (Ebben *et al*, 2005) after which we will discuss the benefits and consequences of integrating them. Lastly we will discuss the peculiarities of the situation under study.

3.5.1 Order acceptance

In a make-to-order situation one has the possibility to accept an order or to reject an order. An order can be rejected for various reasons with differing motives, e.g. the creditworthiness of a customer or the specific order requirements in terms of material, which have nothing do with production control (ten Kate, 1994). However a product can also be rejected because of production control reasons like a perceived lack of capacity to fulfill the request within the needed time period (ten Kate, 1994). The rejection of an order can have various consequences that can have severe impacts. Lewis and Slotnick (2000) for instance discuss the case in which rejecting an order leads to no future orders from that specific customer. The order acceptance therefore has serious consequences. Accepting too many orders leads to overload and an increasing number of late products (Ebben *et al*, 2005), whilst accepting too few orders leads to low utilization rates and less profit.

In our scenario the costs related to the rejection of an order are equal to the costs of late completion of an order, no extra costs are incurred. We do have limited capacity and too many orders. Therefore the production control motive to reject orders is apparent. We should then decide what should form the basis for the decision to accept or reject an order. Either the profitability of the orders or the available capacity can be leading in this decision.

Two general ways can be discerned to control the flow of work through a production process. The first is based on demand, which consist of orders, and in its purest form pushes work into the process without looking at the status of the process. Therefore production systems under this type of control rules are called push systems. The second way is based on the available capacity in the system. Orders are accepted if capacity is available. These rules pull work into the system if capacity is free, hence the name pull systems (Hopp and Spearman, 2000).
Research has indicated that in situations where both push and pull systems can be applied pull systems are favorable. This because pull systems have a lower Work In Process (WIP) for the same level of throughput and therefore lower cycle and throughput times for the same throughput rates. Also a pull system is more robust to errors in WIP than push systems are for errors in release rate (Hopp and Spearman, 2000). In practice of course hybrid systems using both push and pull mechanisms exist and the distinction is not this sharp. For a discussion on the merits and shortcomings of both push and pull systems we refer to Zijm (2000).

The focus should then be on capacity oriented order acceptance. Kingsman (2000) describes input and output control for one machine, first come first served processing and fixed due dates. If the queue plus the input exceed a certain value the due dates can be exceeded, this relation holds regardless of the control method used. This can be prevented by reducing input by rejecting orders, input control, or increasing capacity, output control (Kingsman, 2000). This method of throughput time regulation through input control can also be found in a specific Pull system called CONWIP control (Hopp and Spearman, 2000). In this system WIP is controlled by specifying a upper boundary on the WIP in the system. If this boundary is reached no new products are admitted into the system. This ensures no WIP explosion and thereby controls throughput times. The problem of setting the limit on WIP, known as the WIPcap, and controlling the WIP is referred to in literature as card setting and controlling (Framinan *et al*, 2003). Card setting refers to the setting of a WIPcap level based on certain operating measures whilst card controlling refers to the updating of the WIPcap level based on changes in certain variables such as demand, processing times or capacity. Card setting is widely discussed in literature, but no clear rules have been formulated and the decision generally involves a trade off between desired service level, the percentage of products delivered on time, and the WIP level (Framinan *et al*, 2003). A method used is based on Little's law where the desired throughput and cycle time lead to a WIPcap level (Huang *et al*, 1998). Card controlling is not widely discussed in literature. An extensive review of the literature card controlling and the (dis)advantages of controlling over card setting can be found in Framinan *et al* (2006).

The CONWIP approach, regulating WIP below a certain level which is never exceeded, has shown to perform well in various situations all involving equal products (e.g. Roderick *et al*, 1993). However, its performance when multiple products of different importance need to be processed is, to our knowledge, never examined. In this situation the rejection of some orders is more severe than for others; however the CONWIP system does not discriminate between these orders and thus less lucrative orders can be processed instead of lucrative ones (Van Ooijen and Bertrand, 2003). It is expected that the more often the WIPcap is reached the more severe this problem becomes.

3.5.2 Scheduling

After acceptance, accepted orders should be scheduled to make sure the products are processed in an order that maximizes the profit obtained. In literature numerous different scheduling algorithms can be found with different focuses. Some minimize the total lateness, which is the deviation from the Due Date either early or late, of orders, whilst others focus on the minimization of tardiness (e.g. (Abdul Razaq et al, 1990) (Yang et al, 2004)). In our situation, the number and value of the tardy jobs is the relevant criterion. Therefore we will discuss its minimization in a little more detail.

3.5.2.1 Minimization of the number of tardy jobs

A job is tardy when it is finished after its Due-Date. For some jobs this is worse then for other jobs, since jobs can have different importance. Therefore the tardiness of jobs needs to be weighted when it is minimized. The minimization of the number of tardy jobs on one machine, when all release dates are equal and processing times are deterministic and known can be achieved with the algorithm of Hodgson (Moore, 1968) which is computed as follows:

1. Rank all products on Due-Date, starting with the earliest
2. If no or just one order is late this is the optimal sequence. If not determine the first late order in the sequence
3. Now find the order with the largest processing time in front of the first late order and place it at the back of the queue.
4. Repeat step 2 without considering orders that were placed in the back of the queue.

Lawler (1994) shows this algorithm can be applied when processing times and weights are agreeable, meaning smaller products with smaller processing times have larger weights. Also branch-and-bound methods have been developed for the situation where all products are released on the same day (Potts and Wassenhove, 1988) as well as Lagragean relaxation based heuristics for the situation with equal weight but different release and due dates (Dauzère-Pérès, 1995).

Heuristics for non-agreeable varying weights and different release and due-dates, the more general case, have been developed using Lagragean relaxation (Sevaux and Dauzère-Pérès, 2003) (M'Hallah and Bulfin, 2007) and Genetic Algorithms (Sevaux and Dauzère-Pérès, 2003). However the obtained results for upper and lower bounds, especially when the number of jobs is larger then 100, lead the authors to conclude that the heuristics performance is not guaranteed to be high, especially for weighted cases. Besides this the computational time to solve the heuristics and exact solutions is large, with all discussed heuristics, except M'Hallah and Bulfin's heuristic, requiring more than one hour computing time in numerous cases (M'Hallah and Bulfin, 2007).

A requirement for the implementations discussed above is that products are individually accessible for sequencing and that processing times are deterministic. In case of non-deterministic processing times the solution can still be used, however their performance in terms of optimality might be influenced. If products are stocked in batches none of the discussed algorithms and heuristics can be implemented as such and the situation is severely complicated when the batches do not consist of products of the same importance.

We can however sequence batches on other characteristics which are equal to all products in the batch. In our case this is the entry date and the maximum throughput time of the products in a batch, thus the Due Date of the products in the batch.

3.5.2.2 Due-Date Scheduling

Due Date (DD) scheduling entails that products that need to be finished on an earlier date have priority over products with a later due date and are processed earlier (Bertrand *et al,* 1988). In a case in which all products have equal desired throughput times no difference exists between DD and FCFS scheduling. However if some products have other desired throughput times than others DD scheduling will lead to very different results than FCFS. The performance of the DD rule compared to the FCFS rule is highly dependent on the variation in desired throughput times. The DD rule, and other delivery oriented rules, primarily influences the spread of the throughput time attained. They do not influence the mean throughput time. Bertrand *et al* (1998) show that the spread in throughput time for the DD rule is nearly halve the spread of the FCFS rule at given production circumstances.

3.5.3. Joint order acceptance and scheduling

Since the two control mechanisms are interrelated it might be wise to take scheduling into account when deciding on order acceptance. However this complicates the decision. Ebben *et al* (2005) make the distinction between order acceptance policies and order acceptance algorithms. A policy does not require computations upon the entering of each new product, the decision is based on the state of the system as in the order acceptance literature discussed above. An algorithm does need calculations, for instance to calculate a schedule that incorporates the newly accepted product, which may require extensive computing time. In a policy the order acceptance and scheduling are largely uncoupled, whilst in an algorithm they can be closely interrelated.

Ten Kate (1994) examined the influence of integrating the two in an algorithm compared to the hierarchical approach in which order acceptance is performed first and found that in general there is little difference between the two. Only with short lead times and high utilization the integrated approach outperforms the hierarchical approach. Wester *et al* (1992) arrive at a similar conclusion, in their evaluation of an integrated algorithm and two hierarchical policies. Only if set-up times are large and due-dates are strict the algorithm outperforms the policies.

Nonetheless several contributions have been made to the integration of the two functions, see e.g. Rom and Slotnick (2008) for an overview. However most of these contributions assume known arrivals and deterministic processing times. Besides the dominant optimization criterion is tardiness and not the number of tardy products.

3.5.4. Order acceptance, scheduling: peculiarities of the situation under study

All the discussed literature assumes that when an order is accepted, it also needs to be processed. The possibility of alternative options to fulfill the order and in this way regulate production is not taken into account, probably because this option is not considered feasible. In situation under study this however is feasible. After an order is accepted, it can still be decided not to repair the product after all.

Depending on the way this order is then processed, still by repairmen or by other employees, we could say we can either influence processing time at higher processing costs or outsource the order. Both these options are discussed for related situations in literature.

Lee and Sung (2008) discuss the scheduling problem with outsourcing allowed. They assume a fixed cost per order for outsourcing and a maximal budget for outsourcing and then develop two heuristics to minimize the maximum lateness and total tardiness. In the heuristics they first determine the set of jobs that needs to be outsourced after which they sequence the other jobs. If products are stored in batches however the proposed heuristics become infeasible since products can then not be outsourced individually.

Chen *et al* (1997) discuss the discrete regulation of processing times. They conclude that if the goal is to minimize the number of tardy jobs the problem is NP-hard in line with the scheduling literature discussed above. However they do state an optimal solution exists and give a few characteristics that the optimal sequence needs to satisfy.

Concluding, looking at the model described by Kingsman (2000) in this project besides the input level also the amount of work in the queue can be regulated by not repairing products if too many products are in the queue at the repair department. If all products would be equal this option would not add anything to the order acceptance function, however if products are not equally profitable this permits the preference of more rewarding orders over less rewarding orders when a choice needs to be made in view of the possible late repair of orders.

3.6. Cannibalization & inventory management of spare parts

Cannibalization is defined by Thierry *et al.* (1995) as the recovery of a limited set of reusable parts from products or components. Cannibalization involves the selective disassembly of products to find the reusable parts. The remainder of the product can be processed in different ways.

Cannibalization can be used as a method to obtain spare parts needed for the repair of failed products (Thierry *et al.* 1995). The spare part inventory management system however will be increasingly complicated by the addition of cannibalization. An overview of the literature on spare part management in general can be found in Kennedy *et al* (2002). Spare part management systems involving cannibalization are not discussed in literature. However models involving cannibalization in a remanufacturing situation are discussed, e.g. Van der Laan *et al* (1996).

Van der Laan et al (1996) discuss the extension of normal stockkeeping policies with options to obtain parts from cannibalization and disposal opportunities for these parts. For the extended policies exact expressions for the costs are derived. From the paper it becomes evident that policies using cannibalization as well as the new purchase of parts are more complex that single source inventory systems. If one adds the increased complexity of spare parts inventory management system, it is easy to imagine the complexity of a spare parts inventory management system sourced by cannibalization and new part purchase. The amount of information necessary to develop and maintain such a system is very large and includes the demand for spare parts, the arrival pattern of returns and information on the quality of returns among others.

3.7. Conclusion

The relation of this project to the academic world will be in the field of production control of a make-to-order company. We will focus on the order acceptance function and discuss the differences between the situation in which all products that are accepted need to be processed in the same manner and the situation in which the processing can be regulated on two levels, with zero profit for the fast level, based on the amount of orders accepted. Both systems are regulated by a Work in Process (WIP) based order acceptance policy. Besides this we will examine the performance of a CONWIP like production control system for variable profitability products. Lastly we will discuss the possible improvements attainable by individual stock keeping of orders instead of in batches as forms the base for the systems discussed above.

4. Detailed analysis of the current situation

Under the current decision rules the different settlement/processing combinations defined and discussed in Chapter 2 are used to a different extent. The repairmen as a consequence are performing certain types of repairs on certain types of products and some parts are purchased whilst others are obtained through cannibalization.

First we will examine the magnitude and composition of the warranty return stream and we will examine the time interval between purchase by the user and the filing of the warrantee claim.

Secondly we will look at how the flow is divided over the different claim settlement options and analyze the decision rules used to obtain this division. Here also the processing of Death on Arrival (DOA) failures is discussed.

Thirdly we will zoom in on the repair department, for which we will examine what tasks the repair department is performing and examine its total capacity. After this we will further analyze the tasks performed and the average time needed to perform them. Also the throughput times of the repair department will be analyzed.

Fourthly we will examine the failure behavior of the different product groups. An analysis will be made of the occurring failures and the corresponding repair actions.

Fifthly we will shortly discuss the inventory management of spare parts before we give a synthesis indicating the opportunities for improvement of the present situation.

For the analysis the figures on the returns received in 2006 will be used. These figures, according to RICOLEC, give an accurate representation on the division of products over the different processing options, although the importance of the different groups has changed since 2006. The magnitude of the return flow in 2005 to 2007 is also known, in the discussion on the magnitude of the warranty return flow these figures are used in the analysis.

4.1. Magnitude and composition of the warranty return flow

RICOLEC has received between 18000 and 25000 warranty returns yearly for the last 3 years. There is no clear increasing or decreasing trend in the number of warranty returns. These returns are distributed evenly over the year, although some seasonality can be discerned from 2005 onwards. Peaks in the returns are observed from January to March and in August. The number of returns each month for 2005 to 2007 and the average seasonality factors for the different months are displayed in Appendix 4.1.1. This factor was determined by dividing the number of returns received in each 4 week period by that year's average for 4 weeks leading to a normalized index.

The distribution of returns in a week is not uniform. Tuesdays and Thursdays each account for about 25% of the returns whilst the other 3 days account for equal percentages of about 17%. This is because two large logistic service suppliers deliver returns twice weekly, on Tuesdays and Thursdays. When both effects, the seasonal and the day effect, are deleted from the returns by dividing the received returns by the multiple of both effects, the return flow in 2005 to 2007 can be assumed to be normal distributed with a varying mean for the years but a similar standard deviation, as is shown in Appendix 4.1.2. The distribution characteristics, especially the P-value scores, indicate that the returns can be assumed to come from a normal distribution.

RICOLEC is responsible for and receives the returns from the Benelux. RICOLEC normally offers one year warranty on their products, although CEB products are offered with two years warranty and CED products with three years.

The product portfolio of RICOLEC is large. It covers multiple brands and different product groups (e.g. home cinema, LCD television etc). Next to that products are renewed quite fast in the consumer electronics branch, whilst warrantees generally cover a longer period. This combination leads to a very diverse product type composition of the warranty return flow. In 2006 for instance over 300 different product types were submitted within warranty, at the moment this number is estimated to be around 200.

Within RICOLEC product types are classified within groups based on their functionality and the used techniques, e.g. LCD-televisions and CRT-televisions are two different groups. RICOLEC distinguishes 17 product groups. Table 4.1. lists these product groups with a description of their functionality and the used techniques. The table also lists VCR players. However VCR players are not sold anymore and are also not covered under warranty anymore, but are still repaired on customer demand because of customer service considerations. Some product groups are being phased out (KTV and MP3 players) whilst others (LCDtv and LCD/DVD combo) are getting increasingly important. All product groups consist of multiple product types. The percentage of the total sold products which is returned under warranty, the warranty return rate (WRR), varies between product groups but even more between product types as can be seen in appendix 4.1.3. Within one group WRRs of 1 to 15 percent are observed, the failure behavior, in numbers, is thus strongly product type specific. The different product groups have different average WRRs, and RICOLEC uses different percentages of WRR to judge the performance of products. The percentages are based on the estimated quality of the product. The division of the returns over the different product groups is depicted in Appendix 4.1.4.

Product group	Description
Home cinema	Home cinema systems with DVD and surround sound equipment
KTV	CRT color televisions
LCD	LCD color televisions
Combo lcd/DVD	LCD color televisions with an integrated DVD player
Combo TV/video/DVD	CRT color televisions with an integrated DVD or VCR player
Port.DVD	Portable DVD-players with a small LCD screen
DVD-player	Regular DVD players without sound functionality
Video	VCR players (not for sale anymore)
Audio set	Regular Audio sets with a tuner and CD player
Port. radio/cd	Portable audio sets with a tuner and CD player
Discman	Portable CD players with headphones
Alarm clock	Alarm clock indicating time and with radio functionality
Radio	Normal Radios
Car stereo	Car stereo systems with radio and CD player
Telephone	DECT-telephones
PMR	Personal messaging radios (walkie-talkies)
MP3 player	Portable MP3 players
Other	devices like speaker standards, earphones and other small devices

Table 4.1: Product groups for warranty returns at RICOLEC

The overall average time between customer purchase and the filing of the warrantee claim is 160 days, which is about six months. However we need to split this figure according to the warranty period given to the customer. In Appendix 4.1.5 a histogram in which the period between customer purchase and warrantee is depicted for products with one year warrantee (N=5939 products). These claims are averagely filed after 156 days which is about 5 months and only a very small decline in claims can be found during the warranty period. Appendix 4.1.5. displays a histogram for products with two years of warrantee (N=951 products). Here we see a clear decreasing pattern over the warranty period. These returns can be modeled by an exponential distribution with a mean of 158 days. For products with 3 years of warranty only limited numbers, 30 products, have been sold and sales only commenced in 2006. Therefore the relationship between purchase and warranty can not be analyzed representatively at the moment. It is surprising that the average time between purchase and claim filing is nearly equal for one and two year warranty periods offered. This implicates that offering larger warranty periods does not lead to equally larger costs associated with warrantees.

4.2. Division over the settlement/processing options

4.2.1. Overview

The return stream can be divided into warranty and non-warranty returns. For the warranty returns three claim settlement options are available to RICOLEC, namely repair, replace and reimburse. For the non-warranty returns either a repair or replace proposal is made or nothing is done at all. We will look at the distribution of the total number of returns over these options. Also the product group mix is examined for all the options. Lastly a conclusion will be drawn on the allocation rules used to determine what settlement option should be used.

4.2.2. Repairs not related to claims

Of all the returns received in 2006 only 5% was not covered under warranty. This percentage fluctuated from 4,0% to 6,3% monthly. The product mix of these returns can be found in Appendix 4.2.1 86,7% of the products were sent to the repair department for inspection and a repair/replace proposal.

It is unclear whether a proposal either for repair or for replacement is made to the submitter, since this cannot be seen out of the IRIScodes. However out of the registered IRIScodes it can be concluded that of all the inspected products 50,5% is repaired, 12,0% is replaced and in 33,7% of the cases the proposal is declined. Finally 3,3% of the products is sent back without repair because the submitter fails to accept or decline the proposal.

4.2.3. Warranty returns

The division of the returns under warranty over the product groups can be found in Appendix 4.2.2 Of the 21000 returns received in 2006 95% was covered in warranty.

4.2.3.1. Repairs

Of the warranty covered products 35 to 40% were sent to the repair department for repair, this figure can not be determined exactly because of inconsistencies, e.g. typing errors, or a lack of clarity among repairmen on the meaning of the codes, in the repair administration process. The both estimates are based on different definitions of what constitutes a repair, with the higher estimate including dubious entries that could have been the results from the inconsistencies. Variations between months, when using the 40% estimate, were between 36% and 48%. Figure 4.3 displays the division in product groups of the warrantee covered repairs.

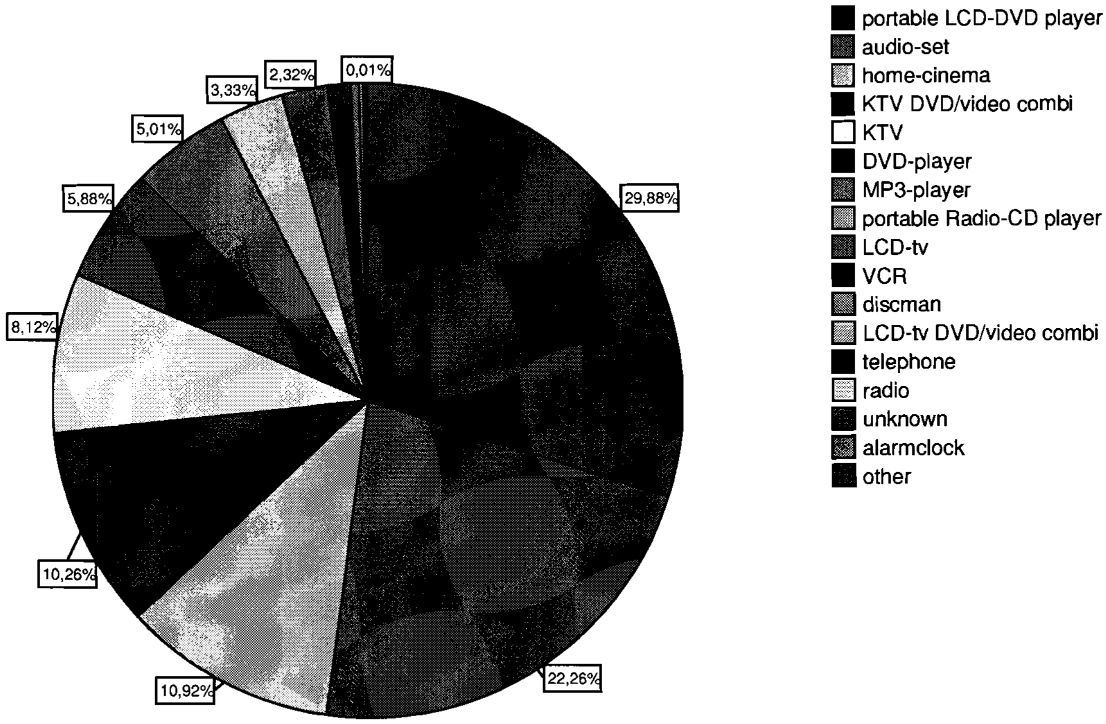

Fig. 4.3. The division of the repaired warrantee returns in product groups

4.2.3.2. Product replacement and reimbursement

60 to 65% of the warrantee returns were not repaired. Of these claims 75% was settled by financial reimbursement and approximately 15% was settled by replacement of the product, the settlement options chosen for the other 10% is unclear. The division over the product groups can be found in Appendix 4.2.3

4.2.4. Allocation rules

The allocation rule used to identify whether a product is a warranty return or not is straightforward. It depends on whether the warrantee period has expired and whether the product was used in a normal manner by the customer, although this is very hard to verify. The allocation rules that determine how to process warranty claims on the other hand are not so straightforward. Here we make the distinction between repair and the other two options. The allocation rules used to determine whether a product should be replaced or reimbursed could not be explicitly derived from the available information on the processing of products. In practice this decision is taken based on specific customer preferences and/or the inventory situation of new products for the specific product type since a product must be available in order to be able to replace it. Often it is difficult to replace a product because only newer versions of the product are available. These versions are seldom accepted by the submitting companies. This leaves only the option of financial reimbursement open to satisfy the warranty claim.

The decision whether to repair a product at a first glance seems to be taken on a product group level. Some product groups are considered for repair more often than others. The product groups most often sent to the repair are Home cinema (92,5% of the arrivals), LCD (92,1%) and portable DVD (91,1%). Other product groups often sent to the repair department include KTV, Combo TV/video/DVD, audio-sets, VCR, DVD-player and combo LCD/DVD. For the other product groups repair is undertaken on less than 30% of the returns. The full results per product group can be found in Appendix 4.2.4. A closer look reveals that the decision whether to repair a product or not seems to be taken on product type level. In the KTV and audio-sets categories for example, some product types are repaired very frequently whilst other types are not repaired at all. The results for each product groups' product types can be found in Appendix 4.2.4

Because of the existence of Death on Arrivals (DOA), which are never sent to the repair department, the percentages sent to the repair department of most product types generally considered for repair do not equal 100%. As noted in the second chapter, the processing of products classified as DOA is different from 'normal' return processing. These are not repaired, even though other failures of the same product type are repaired. Also the processing options for DOA's are more diverse. They can be cannibalized, sold secondhand or repaired with the intention of making a new sale. This last option, according to the repairmen, is currently never used. The quantity and manner of processing of DOAs cannot be analyzed from the available figures.

4.3. Capacity, tasks & performance

The tasks in the return processing are performed by two departments. The arrival and the handling of not-repaired (warranty)returns is undertaken by the collection department. The repair of products, whether under warranty or not, is done by the repair department. This department also cannibalizes products to obtain spare parts. Here we will first shortly examine the tasks and performance, in terms of throughput time, of the collection department. After this we will examine the capacity, tasks and performance of the repair department.

4.3.1. The collection department

The collection department is generally staffed by one person except on Tuesdays and Thursdays, when two persons are employed. This because more returns arrive on these days. At the collection department ample capacity is present to register all claims arriving on a day the same day. The take in process was already sufficiently described in section 1.2.1. of this report.

The further processing consists mostly of administrative tasks, the exception being when a replacement product needs to be taken from stock, wrapped and made ready for transport. The precise process and its parts is not part of our research and therefore will not further be examined. However we will take a short look at the throughput times of the products completely handled by the collection department, to examine whether these products are processed within the maximum throughput times stated by RICOLEC's customers. The throughput time for these claims is small. In general these claims are processed immediately or shortly after arrival. This because it is an administrative, not time consuming, task consisting of booking the product in and ensuring financial reimbursement for the submitter. However it can be that because of incomplete products send in with the claim or other difficulties this time is severely lengthened. Overall 50% of the claims is handled by the collection department within 4 days and 91% is handled within 14 days, thus within 10 working days. The delay is mostly caused by the incorrect filing of customers.

4.3.2. The repair department

The repair department does not have ample capacity to repair all (warranty)products. Besides this the department has some other tasks to perform as well. Here we will first look at the tasks executed by the repair department. Then the available capacity and its division over the tasks are examined. Lastly we will look at the performance of the repair department in terms of throughput time.

4.3.2.2. The tasks

The tasks performed by the repair department are:

1. The repair of products under warranty
2. The inspection and repair of products out of warranty
3. The cannibalization of products to obtain spare parts

We will briefly explain the steps and their durations in each of these tasks.

4.3.2.3. Repair under warranty

As described in the first chapter the repair of products under warrantee consists of several steps. These steps are: getting the product from the container, unwrapping the product, look up the product in the database, inspect and repair the product, wrap the product, finish product administration and put the product back in the container. In this process the inspection and repair step is dominant from a time perspective. The time needed for the other steps is very limited. All the other steps together take an average of 3 to 4 minutes. This time is fairly constant.

The repair and inspection step can be further subdivided. First a product is connected, then the complaint is checked. Depending on the complaint and whether it is detected further actions are taken. Most of the times an attempt at repair is made. This attempt involves opening the product, repairing or replacing the broken parts and closing the product again. After this it is checked whether the defect is solved. The connecting and checking of the complaint takes about 1 to 3 minutes and the check whether the defect is solved takes 1 to 5 minutes. Products for which the complaint is not found are not opened, but their functions or specifications are tested. The time needed to open and close the product is highly variable among product types and constitutes a major part of the total repair time. The time needed for the repair of the defect is highly variable among product groups and dependent on the size of the products. In larger products (LCDtv, DVD-players etc.) it is easier to find the failing components than in small products (Portable LCD-DVD players) where all the components are fitted in very closely and it is often necessary to remove working parts to get to the failing parts which is very time consuming. If an attempt is taking about 30 minutes and still no end is in sight the attempt is ended and the claim is settled by different means. The product is either stocked for cannibalization (50%) or sold secondhand (50%). Only very rarely a product is disposed of. All in all it is estimated that 30 minutes per product is a very rough but useful estimate. The specific time needed to solve a specific repair on a specific product will be examined in section 4.4.

4.3.2.4. Repair out of warranty

When a product out of warranty arrives at the repair department first a proposal needs to be made for repair or replacement of the product. During the inspection to make the repair or replace proposal the section of failure and the defect are classified, the time needed for this is estimated by the repairmen to be only 2 or 3 minutes, because the products are most of time well known by the repairmen. Whether the repair is actually undertaken depends on the acceptance of the repair proposal. If the repair is undertaken it goes along the same lines as the repair of products under warranty and on average these repairs will take roughly 30 minutes as well. As was explained earlier these repairs are always successful.

4.3.2.5. Cannibalization for parts

Due to the extensive and rapidly changing mix of products sold by RICOLEC the list of parts incorporated in these products is very large. On the other hand the demand for parts is unknown beforehand since the failure behavior of a product is unknown. Therefore RICOLEC does not stock all these parts abundantly. The spare part inventory management and the use of cannibalized parts are further discussed in section 4.5.

To obtain spare parts that are not in stock cannibalization of products is used. The cannibalization is performed during the repair of a product if the necessary part is not on stock, or in quieter times between repairs.

Cannibalization involves the removal of useful parts out of a nonfunctioning, not-repairable (or at least not by RICOLEC) product. Products considered for this are labeled so by RICOLEC. Cannibalization of a product costs roughly 15 minutes per product and can yield multiple parts, but most of the time only one part is useful. It can be assumed that all cannibalized parts are eventually used in the repair of a product. The remainder of the cannibalized product is disposed of at no extra cost.

4.3.2.1. Capacity & utilization

As stated in the second chapter, two fulltime and two part-time repairmen are available for the repair of submitted products. Together, in 2006, all the repairmen worked for about 600 days which is equivalent to 4800 hours. This is the net amount of worked days, vacation and sickness leaves are already subtracted. It is unknown how these hours were spread over the year, which is assumed to have 250 working days. There are no possibilities for overtime and it is impossible to acquire new workers on a temporary basis due to the technical nature and specialization level of the repairs, so the capacity is fixed on the stated level. Leaves are generally known about 1 to 2 weeks ahead, but are generally not coordinated among workers. A leave request is usually granted.

Everyday, according to the repairmen, a total of on average 2 hours a day is needed for logistical operations involving batches of repaired goods. Subtracting this 2 hours a day leaves 4300 hours to perform the tasks assigned to the repair department.

In 2006 35 to 40% of the returns under warranty were repaired. This corresponds with between 7000 and 8000 repairs. Of all the returns not under warranty 50,5% was repaired. This results in about 500 repairs not under warranty. These two repair tasks together require, based on the rough estimate of 30 minutes per repair needed according to the repairmen, between 3750 and 4250 hours of repair department capacity. Cannibalization of parts is not registered. The repairmen estimate that for 2007 40% of the used parts were acquired through cannibalization. For 2006 they were not able to recollect the situation to provide such an estimate. On the other hand it is unknown how often parts were used in the repair of products, because this is not registered in the system. The repairmen estimate that in 2007 about 3000 parts were used. This excludes small parts like diodes or transistors; however these parts are never cannibalized. Extrapolating the estimates to 2006 roughly 300 hours was used to cannibalize products in 2006.

Comparing the available capacity (4300 hours), with the estimated needed capacity (between 4050 and 4550 hours) the conclusion is that the available hours are utilized fully.

4.3.2.6. Performance: throughput times

For cannibalization of products for parts and repairs of products not covered under warranty performed by the repair department no performance or throughput times could be measured. For cannibalization no adequate performance measure is present and data is lacking. For repairs outside of warranty throughput times include the time between making a proposal and acceptance of the proposal. This time is customer dependent, highly variable, some customers reply within one day others never reply at all, and, on average, larger then the 10 day maximum allowed for repairs covered under warranty.

The throughput time of repairs under warranty could be extracted from the data. In the analysis the cases with a throughput time larger than 50 days were assumed to be the result of either administrative errors or other uncontrollable peculiarities and were therefore deleted. The overall average throughput time is 10,73 days with 87,9% of the products repaired within 14 days which equals 10 working days.. However the throughput time does vary strongly throughout the year. Figure 4.5 displays the mean throughput times in the different months. There seems to be no direct relation between the arrivals and the processing time. The number of to be repaired warranty returns each month is displayed in appendix 4.3.2

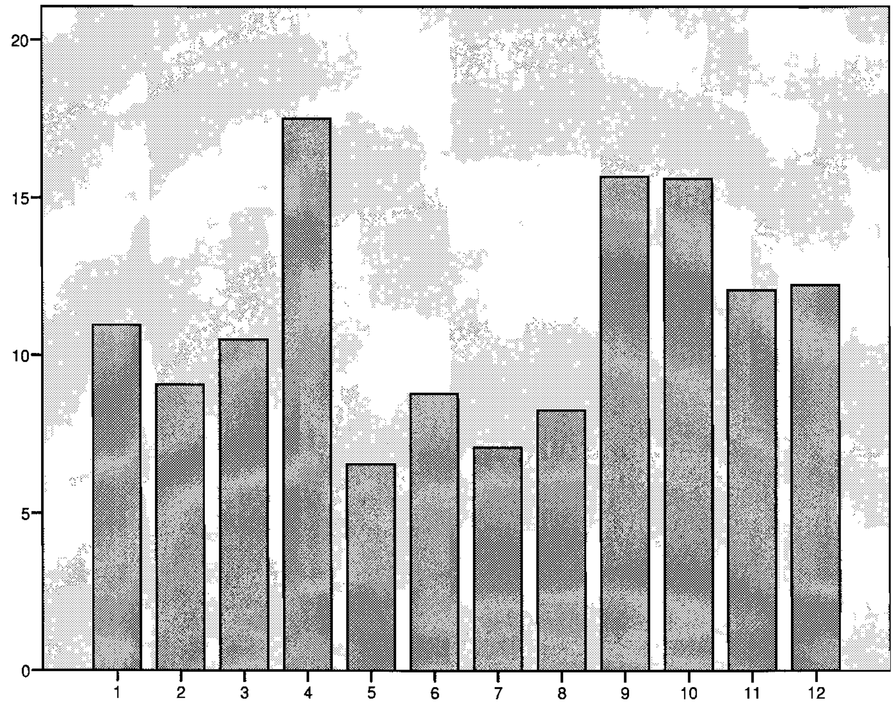

Fig. 4.5 the mean throughput time (days) in the different months for repairs under warranty

Since repair is undertaken in a first come first served manner it was expected that the throughput time of the different product groups does not deviate strongly from the overall mean. An analysis of the throughput times per group of the portable LCD-DVD player, Audio set, home-cinema, KTV DVD/Video combo, KTV and DVD-player groups indicated that the mean throughput time per group varied from 10,18 to 11,82 days and the percentage of products repaired within 14 days varied between 91,8% and 81,9%. According to RICOLEC this is due to the variation in the arrival pattern of the different product groups over the year. Portable LCD-DVD players for instance, due to their usage on holidays, are often returned after the summer months in September and October causing a slightly higher throughput time of 11,82 days.

4.4. Product group failure behavior

To obtain insight in the failure behavior of the products we have analyzed the IRIS-code data available for 2006 for the repaired returns, under and out of warranty. The results per product group are discussed below. In the product group discussion peculiarities in the repair of that group will be discussed. We will also give indications on the average repair time of the product group and its variability across different product types and failure combinations. These indications are based on interviews with the repairmen, since no repair times are registered.

4.4.1. Within warranty products

For the dominant (portable LCD-DVD player, Audio set, home-cinema, KTV DVD/Video combo, KTV and DVD-player) product groups covered under warranty in repair the failure behavior will be discussed. These product groups together constitute over 95% of the repaired products. First a general analysis will be made of the repairs after which the most frequently occurring section of failure, defect and repair combinations will be discussed and listed, indication of processing times are also given. These are analyzed based on the IRIS-codes registered by the repairmen. Sections, defects, repairs and combinations are listed in the text when they account for more than 10% of the total. Also the probability of successful repair and the throughput time division are determined. We will end with an aggregation of the results over the different product groups. The complete results for the analysis of product error combinations can be found per product group in the appendix 4.4.1. The analysis of the repair times and the repair process is based on interviews with the responsible repairmen.

4.4.1.1. Portable LCD-DVD player

The dominant sections are the disk-drive mechanism (32,7%), the system control section (29,2%), the power supply unit (13,7%) and the information display section (11,3%). The observed defects are predominantly general (indicating that the failure cannot be adequately described by one code) (17,5%) or caused by failure of an electric component or module (52,3%). The dominant repairs undertaken are replacement of the failing part (56,1%) and the control of functions (15,2%). The most frequent combination of options is a failing disk drive caused by a failure of an electric component which therefore is replaced (23,8%). Of all repairs undertaken on portable LCD-DVD players 98,4% was successful.

On average the repair of a portable LCD-DVD player costs about 25 minutes. This time is highly variable between product types, repairmen estimate that for different types between 15 and 40 minutes is needed, because of differences in the time needed to open the product, and fault types, because of the amount of parts collected on a small surface.

4.4.1.2. Audio set

The dominant sections are again the disk-drive mechanism, the system control section and the power supply unit with 38,9 15,0 and 12,8% respectively. The defects classifications are failure of an electric component (36,7%), general (24,8%) and no fault found (15,7%). The dominant solutions are replacement (56,1%) and the control of functions (11,9%) or specifications (10,9%). The most frequently occurring combinations is a failing disk drive caused by a failure of an electric component which therefore is replaced (16,4%). The success rate of repair on audio sets is 95,3%.

The time needed for the repair of an audio set is 30 minutes on average. This time is not highly dependent on the type of failure and its repair. It is however highly variable, between 15 and 45 minutes, among product types due to differences in the time needed to open and close the set.

4.4.1.3. Home cinema

The disk-drive mechanism is the most frequent failing section with 41,7% followed by the system control section (16,5%), general failures (12,1%) and analog audio processing (11,6%). The most frequently observed defects are defects of electrical components or modules (39,2%), no fault found (27,0%) and general (17,5%). Replacement of product parts (52,6%) and the testing of functions (20,1%) and specifications (16,3%) are the dominant repairs. Again a failing disk drive caused by a failure of an electric component which therefore is replaced (23,7%) is the most observed combination. The success rate is 97,8%.

The average repair time of a home cinema set is roughly 30 minutes. This time is highly variable among different failure types, varying between 15 and 40 minutes. There is only minor variation among product types.

4.4.1.4. KTV DVD/Video combo

The dominant failure sections are the disk-drive mechanism (47,7%), the power supply unit (16,5%) and general (11,5%). The failures are a failing electrical component (47,5%) and no fault found (29,1%). The dominant repairs undertaken are replacement (52%) and the testing of functions (22,1%) and specifications (14,5%). The dominant combinations are a failing disk-drive mechanism (25,5%) or power supply unit (12,5%) which are caused by failing electrical components which are replaced. The success rate for repair is 98,2%.

On average the repair of a KTV DVD/Video combo takes about 35 minutes. There is not a lot of variation among failure types or among product types. However there is a strong learning curve present for failures in the television section due to the technical nature of conventional KTVs and the difficulty of finding the part that caused the failure on the first products. Finding this part becomes easier with experience.

4.4.1.5. KTV

The most failing sections are the power supply unit (38,9%), the system control section (16,3%) and general failures (13,0%). The dominant defects observed are a defect electrical component or module (42,8%), general defects (16,7%) and no fault found (15,4%). The undertaken repairs are component replacement (54,1%) and testing on functions (12,7%). The dominant combination is a failing power supply unit because of defect electrical components which are therefore replaced (23,6%). 96,4% of the repairs are successful.

The average repair of a KTV takes roughly 35 minutes. Not a lot of variation is present among product types or failure types. However, like for KTV DVD/Video combinations a strong learning curve is present between subsequent repairs.

4.4.1.6. DVD-player

Four sections account for more than 10% of the failures each. These are the disk-drive mechanism (26,3%), the system control section (24,9%), the power supply unit (18,2%) and the remote control (11,5%). The most observed defects are a failed electrical component (36,0%), no fault found (21,1%) and general failures (20,9%). The most frequently undertaken repair actions include replace of the component (53,3%) and testing on specifications (15,7%) or functions (13,7%). The most observed combinations are a failing power supply unit (12,4%) or disk drive mechanism (10,3%) both because of failure of an electrical component which is then replaced. 96,4% of the repairs are successful.

The repair of a DVD-player takes about 20 minutes. There is not a lot of variation between product types or failure types.

4.4.1.7. An aggregation

As can be seen, most failures occur in just a few sections. This is not product group dependent. The disk drive mechanism, if a product has one, is very vulnerable. Looking at other product groups that are repaired this observation is confirmed. For VCRs the major section of failure is the tape-drive mechanism (84,1%). According to the repairmen the moving character of the respective sections makes them vulnerable. Overall the disk-drive and tape-drive mechanism together account for 33,7% of the failures. Other sections frequently causing problems are the system control section (19,4%) and the power supply unit (14,8%), although general failures also occur regularly (10,9%). The overall ranking for defects is also in line with the above results. 30,6% is caused by a failing electrical component or module, 29,5% has a general cause and in 19,3% of the cases no fault is found. The undertaken repair actions are the replacement of a component (52,6%) and the control of functions (18,5%) and specifications (10,5%). There is only one overall combination accounting for more than 10%, this combination is, not surprisingly, the failing disk-drive mechanism because of failure of an electrical component which is replaced (12,2%).

The overall success rate of repairs is 96,9%, however it must be noted that the repairmen, based on their experience with the repairs, state this rate to be lower. This because they sometimes swap a failed repaired product with a product from cannibalization stock, this is not registered in the figures and therefore seen as a successful repair while it is not.

4.4.1.8. Within warranty products: sales value distribution

Not every product that is returned is equally expensive and thus the costs for replacement or reimbursement or not equal for all returned products. This makes repair more profitable for some products than others. Here we have examined how the sales value of the repairs is distributed over the different months in the year.

To obtain the distribution of the profitability of repair we would need the sales prices of all returned products in 2006. This information was not available. Therefore the sales price distribution was estimated based on the prices of several product types of each product group. The product types were drawn from the returned product types in 2006 and were checked on their representativeness for the product group with respect to the sales prices with RICOLEC. With these prices average prices for each product group were constructed. The returned products covered under warranty were classified in four and six levels based on the sales price information available. The distribution of the levels in percentages of the total returns varies only slightly in the different months of the year. If four levels in the sales price were distinguished the maximum spread in percentage of the total returns within one level was 13,2%. If six levels were used this number increased to 15,1%.

4.3.2. Products outside warranty coverage

Here we will discuss the frequently occurring failure sections and defects. The dominant sections are similar to the repairs within warranty. The disk-drive mechanism (29,2%), the power supply unit (20,7%) and general (17,9%). The observed defects do differ slightly from the defects in warranty returns. The most frequently observed defect is still a failure of an electrical component or module (30,2%) and general defects are also frequents (18,3%). However wear out of a component causing low performance (20,8%) and mechanical breakages (13,9%) constitute important defects as well.

The products that are repaired are repaired mostly by the replacement of worn out or failed parts (87,8%).
The full results for the failure repair combinations of products out of warranty coverage processed by the repair department can be found in Appendix 4.4.2.

4.5. Spare part inventory management

As stated earlier, no registration of spare parts used is in place. In the past registration was performed for sometime, but it was discontinued because of the constant errors made in the registration. Still we can provide some estimates on the spare parts usage and the value of the spare parts. In 2006 for roughly €60000,- was purchased in parts, this includes all modules and parts of non-negligible value so also for instance remote controls that are sold separately. This excludes bulk parts as transistors or diodes, but their value is very small and can be neglected. These parts are not considered further in this project. In the IRIS-classification it can not be seen which part is used if a replacement is done. Therefore we will use estimates provided by the repairmen based on their experience during repair. They are also responsible for the inventory of parts, although they do not order the parts, and therefore they have knowledge on which parts are in stock and used.

The repairmen estimate that about 70% of the components used are laser units. For 2006 an estimate of 2000 used laser units is made. In general about 10 to 15 types of laser units are used in the repair of products, these are only rarely interchangeable. The other component used frequently is a software-board (20%), which is a printed circuit board. There are numerous types of these boards, RICOLEC uses more than 20 types in their repairs, but not for all devices boards are available at RICOLEC. Lastly power supply units are used, but far less frequent (5%), often the power supply unit is incorporated on the software-board.

The repairmen estimate that they currently get 40% of their spare parts through cannibalization of other products. However they are not able to give a funded estimate for 2006, because they are not able to recall how often they cannibalized products then. Sadly it was not possible to determine whether a product was put in stock for cannibalization or in stock for secondhand sale when it was decided that the product was not repaired. Therefore we do not know what was put in stock for cannibalization directly. On the other hand we also do not know what products were put in stock for cannibalization by the repairmen when a repair fails. Totally we can not give any estimate on the cannibalization inventory, or its use in 2006.

Lastly an estimate can be given of the out-of-stock probabilities of spare parts. This figure indicates the percentage of times a repair can not be performed because no spare parts are available, neither in normal nor in cannibalization stock. This percentage is estimated by the repairmen to lie between 2 and 5% of the total number of repairs. This includes only the repairs that normally are performed.

4.6. Conclusion

Currently, most products are repaired within 10 days and in general the more expensive products are repaired with high success rates. With a goal of the repair of a maximum total sales value of the products within the maximum throughput time of 10 days it must be concluded that the overall functioning at the moment is not bad. However no guidelines are present nor followed. The functioning is based solely on the experience of the repairmen, leaving multiple opportunities to improve upon the performance besides the possibility to introduce decision rules in order to structure the repair process. In the redesigns of the process in the subsequent chapters we will focus on forming decision rules that guarantee a high value of products repaired within the maximum throughput time taking into account different possible supply situations, in terms of numbers of returns and the value of returns, RICOLEC can be facing in the future. With these rules it is tried to overcome the following shortcomings evident from this analysis

1. The selection of products for repair, thus which products to repair. Currently the time needed for the different repairs is not incorporated in the decision whether to repair or not, which may lead to suboptimal allocation of repair time, since cheap but fast repaired products can possibly be more profitable to repair than expensive but time consuming products. At the moment it is thus not clear whether the right products, from the viewpoint of money saved on reimbursements, are repaired. Also the information on the ease of repair which is gathered during the first product test before a product is included in the assortment is not used in the repair planning process, while this information can be of use in the planning of repairs.
2. The control of throughput time of the products sent to the repair department. Throughput time currently is not explicitly controlled nor considered when products are sent for repair, therefore the amount of products repaired late, although not high at the moment, can change drastically under changing circumstances. This needs to be controlled in the redesigns.
3. In the current process no distinction is made between the returns on the maximum throughput time whilst this differs between returns. For most returns, 70%, the failure to settle the claim within 10 days renders the repair of the product useless since it has to be monetarily reimbursed anyway. For the other 30% no such strict number of days is present although a throughput time of 10 days is aimed for by RICOLEC, RICOLEC expects that when throughput times exceed 15 days these customers demand financial reimbursement.
4. With respect to the inventory management of spare parts the conclusion is that no real management exists. However the money spent on spare parts is only a very limited amount and the results are, in the form of out of stock probabilities, acceptable. No guidelines to decide what products to stock for cannibalization are present.
5. Also the replace or reimburse decision motives are not insightful and this decision is largely made to achieve customer satisfaction. However the cost associated with the decision options are not registered, nor taken into account.
6. Lastly no insight is gained in the failure behavior of product types that are not considered for repair. The insight obtained in products that are repaired is not reported in a structured manner. Because of this the suppliers of RICOLEC cannot be informed about or held responsible for (poor) product performance.

The first three conclusions deal with the decision what to repair and what not to repair. The fourth conclusion deals with the decision what to cannibalize. The fifth conclusion focuses on the decision whether to reimburse or replace a product. Finally the last decision reveals the lack of insight in the quality of products that are not repaired.

Chapter 5 gives an overview of the different redesigns, which are then explained in more detail in the Chapters 6 to 11.

5. Outline Redesign

The different redesigns try to overcome the shortcomings explained in the conclusion of the preceding chapter. To do so the process, as displayed in chapter 2, is modified. The new model is displayed in figure 5.1. The test transition was added to the model, as indicated in the ellipse in the figure. This indicates the possibility that a product is tested when it is not repaired to gain information on the failure of the product.

The redesigns made for the problem can be divided into different parts, each covering an aspect of the process and each focusing on one of the decisions necessary in the process. We will, in the redesigns discuss the decision whether to repair, the decision whether to test, to cannibalize and how to settle the claim. We will explain the different parts in detail, explaining the reasoning behind the proposed decision rules, in the subsequent chapters. In these chapters the research questions posed in Chapter 2 are implicitly answered.

In the model we assume that the decision involving repair is always taken before the other decisions as indicated in the flow model depicted in figure 5.1. With this the implicit assumption is made that it is always more valuable to repair a product then to cannibalize it. This might not be the case when the parts that can be used from a defect product are together more valuable than the repaired product. However it is expected that is will only very rarely be the case because every product, when cannibalized, delivers only one and sometimes two parts. Also this assumption implicates that repair is found more important than testing a product. However if a product is repaired it is automatically tested. If a product is not repaired after all, the decision to test can still be taken. This sequencing of the decisions on the other hand greatly simplifies the problem and makes it easier to design implementable solutions.

The different parts of the redesign will be discussed in the subsequent chapters. Chapters 6 to 9 will focus on the decision whether to repair or not, and present different redesigns focusing on decision procedures that improve upon the present situation. With these redesigns an answer is given to the research questions on what and how much to repair. The shortcomings discussed in the first three conclusions discussed in section 4.6 are incorporated in the redesigns.

Currently the decision whether to repair a product is taken at intake. If the decision is to repair then an attempt at repair is always undertaken. This creates a dilemma. On the one hand we have to make sure products are repaired before they are due so we have to limit the amount of products sent to the repair department, thus controlling throughput times. On the other hand we do want the repairmen to be busy all the time, so we have to make sure there are always products to repair present at the repair department. To do so we have to make sure a lot of products are sent to the repair department, which contrasts the earlier requirement. In the current situation the throughput times are regulated by means of measures based on the number of days the eldest product is in inventory and products are primarily in order of arrival although occasionally this order is not followed, why and on what base is unclear and not registered. Also the selection of products for repair is improved in the redesigns. A last characteristic of the current situation is that products are placed in carts and cannot easily be accessed individually when in stock, therefore decisions what to repair are taken on a cart/batch basis. These characteristics will be looked into in the design of a solution. However, in all redesigns capacity is assumed to be given and limited. Limitations of capacity, which can occur from, for instance, voluntary leave of employees or retirement, are only briefly considered when discussing the performance of the different redesigns. Totally 4 different redesigns are considered. They are discussed in order of increasing complexity, e.g. their deviation from current practice.

In Chapter 6, the first redesign takes the current situation and extends it by including product based workload regulation, however without a fixed maximum capacity of the WIP, and a refined base for the selection of repairs. An extension of this redesign with priority rules, Redesign 1b, is also discussed. Redesign2, discussed in chapter 7 extends the first with a WIPcap, that makes sure no more then a certain number of products is accepted, thus the WIP has a fixed maximum. This prevents products from being repaired too late. Redesign 3, discussed in chapter 8, differs from the previous redesign because it includes the possibility that products, after a first decision to repair, are not repaired after all and the claims are financially reimbursed. Lastly chapter 9 will discuss the fourth redesign in which products are accessed and scheduled individually at the beginning of each day instead of in batches upon arrival. The redesigns partly build on each other. For each redesign only the features in which it deviates from the previous redesigns are discussed.

Finally Chapter 10 will focus on the test decision incorporating the sixth conclusion of section 4.6 and answering the research question how to obtain insight in the failure of not-repaired products. Chapter 11 will discuss the cannibalization and replacement/reimbursement decisions, incorporating the fourth and fifth conclusion of the previous section and providing answers to the research questions associated with these decisions.

Chapter 12 discusses the settings of a simulation used to compare the first three redesigns for the decision whether to repair a product or not. The results, together with analytical analysis will be used to judge which of the redesigns is best under which situations. This is discussed in chapters 13 to 16.

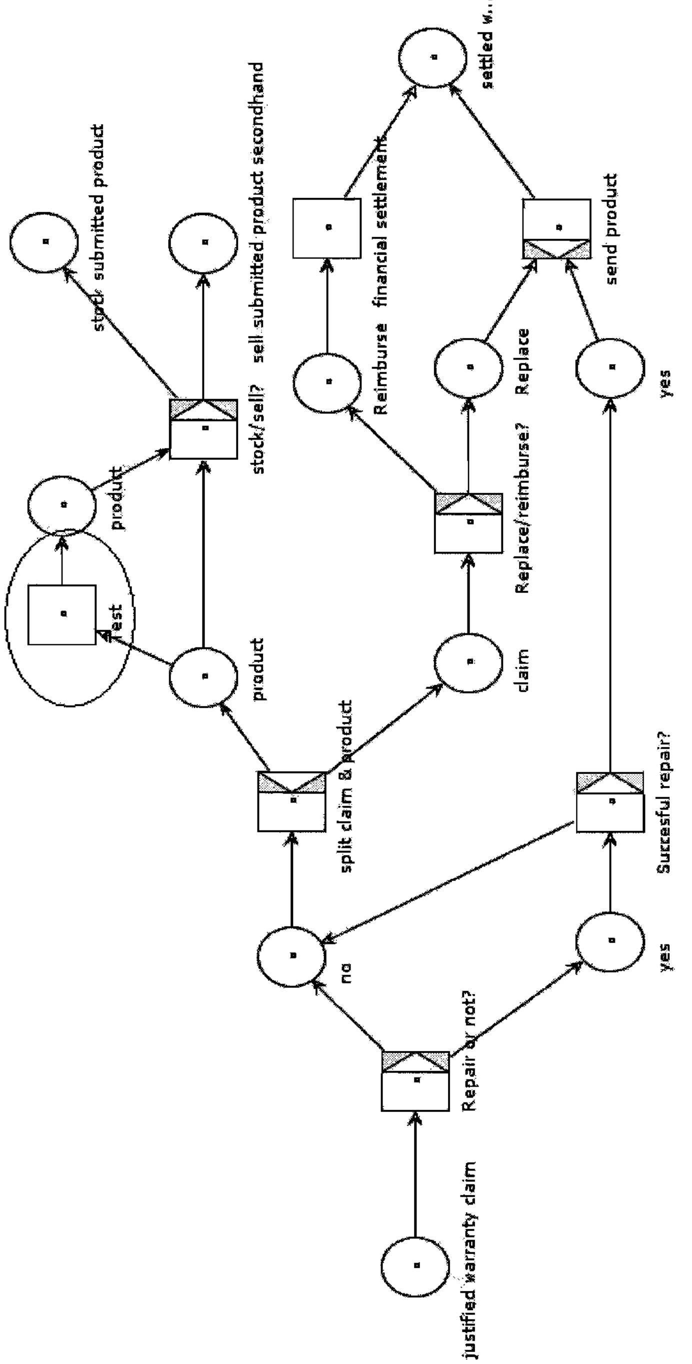

Fig 5.1.: Redesigned flow model

6. Repair or not? Redesign 1: repair selection & throughput time control

Currently the decision to repair or not is taken at intake. If decided to repair an attempt is always undertaken. The sequence in which repair is undertaken is first come first served (FCFS), although some unclear priority rule is sometimes applied.

6.1. Redesign 1: Rationale

The current situation is the result of numerous years of experience. The decision procedures used were not designed explicitly but are the result of a lot of small, unstructured, steps. Although the in the current situation already over 80% of the, usually more expensive, products is repaired on time, as was indicated in section 4.6, still the selection and control mechanisms used can be improved upon without changing the structure of the process. This redesign looks at the used mechanisms and tries to improve and formalize them. For three mechanisms alterations are suggested. First for the regulation of the throughput time, second the selection of returns sent to the repair department. Lastly, in redesign 1b for the sequencing of returns in the Work In Process (WIP). The differences between the current situation and the redesign are explained in the separate paragraphs. We will conclude with a synthesis of the different changes which completes the redesign and a discussion of the practical changes needed to implement this redesign.

6.2. Redesign 1: Throughput time regulation

6.2.1. Current: due date based WIP control

The amount of work in process is regulated by the repairmen. If they observe that the throughput time of the products to be repaired is increasing to beyond a number of days, around 13 days, they tell intake to send less products to the repair department. If, on the other hand they observe that the throughput time of the product in the WIP is only a few days, around 3 days, they tell intake to send more products. Which products are sent is determined based on the value of a product, expressed in the cost price, which is calculated by adding RICOLECs costs to the purchasing price. If more products are needed, in periods with fewer returns, some cheaper products are also sent and if fewer products are needed, in periods with more returns, only more expensive products are sent.

This method of regulation does not take into account the number of products in the inventory, only the number of days products have been in the inventory by looking at the entry date labels attached to the carts by the collection department. Because the number of products per day varies this can lead to errors since the throughput time is determined by the amount of products in inventory and the available capacity, not by the number of days the earliest received product is in inventory. Therefore we propose to control WIP based on the amount of products in the WIP and capacity.

6.2.2. Redesign 1: Product & capacity based WIP control

Since all work that is sent to the repairmen needs to be repaired because once the decision to repair is made it cannot be changed we can only directly control the average throughput time by controlling the amount of work in the queue, thus the amount of work sent to the repairmen. In this redesign a CONWIP like strategy is chosen, however no strict maximum is set for the queue length, also named WIP.

The throughput time of a product consists of two main elements. The processing time, which is the time necessary for repair, and waiting time, which is the time the product is in the queue. The processing time is generally very small compared to the waiting time. The waiting time consists of two main components; the time until the product presently under repair is processed, which is the remaining service time, and the total processing time of all products in front of the product in the queue. However, since on average 2 to 3 repairmen are working and the average repair time is around 30 minutes the remaining service time averages about 5 minutes and thus is very small compared to the time needed to process all products in the queue, since in the queue multiple days of work are waiting normally.

We do not know the total processing time of the waiting products since their processing times are variable. We only know the mean processing time, which deviates between product groups and error types, but overall equals 30 minutes. Based on the information on the processing time acquired through the interviews with the repairmen we assume the repair times of a random product to be normally distributed with mean, μ_p = 30 minutes, and standard deviation, σ_p= 5 min (assumed based on the information on the spread in repair times given by the repairmen), and that processing times of products are independent from each other.
The average minutes work in process in the queue now becomes:

$$\mu_{MWIP} = n * \mu_p \tag{6.1}$$

And the standard deviation becomes, in minutes:

$$\sigma_{MWIP} = \sqrt{n} * \sigma_p \tag{6.2}$$

With:
n = number of products in the WIP, excluding products under repair
MWIP = minutes work in process

Capacity consists of the personnel, repairmen, available to repair products. However repairmen do not only repair products. They also need time to transport products and control batches; this is assumed, based on the interviews with the repairmen, to be a fixed 2 hours per day in total. Next to that they also need time to cannibalize products to obtain parts. Capacity to repair and cannibalize then is defined as:

$$CAP_{rep,x} = (\textstyle\sum_{i,j}^{x,4} k_{ij}) - 2 \times x \tag{6.3}$$

Where:
$CAP_{rep,x}$ = capacity for repair and cannibalization at the repair department in the next x working days (hours)
i = days, from 1 to x
x = maximum throughput time of products set by RICOLEC, in days
j = repair men, from 1 to 4
k_{ij} = number of hours repair capacity per worker per day

The second factor, $2 \times x$, displays the hours needed for transport and control of batches in x days, these need to be subtracted from the capacity.

Cannibalization for parts is mostly performed during the repair of a product. If a repairman sees the needed part is unavailable he takes a product stocked for cannibalization and gets the part from that product, after this he continues with the repair of the to be repaired product. This time is not included in the repair time per product. Whether cannibalization is needed is not known in advance. Cannibalization is performed in about 40% of the cases where a part is required, which is in about 40% of the repairs. Therefore cannibalization is needed in 16% of the cases. Cannibalization, according to the repairmen, requires 15 minutes per attempt. We have to subtract this capacity from the total capacity available for repair, since both tasks are executed by the same personnel. Including this, the probability that on a newly arriving product repair is started within x days then becomes, under FCFS service discipline:

$$P(MWIP < (CAP_{rep,x} - 0{,}16 \times n \times 15)) \tag{6.4}$$

With:
$CAP_{rep,x}$ = the capacity for repair of warranty products in the coming x days

RICOLEC aims for a throughput time of 10 days for all products. In order to be 95% sure a newly arriving product is repaired within 10 days the WIP should be kept under the level of:

$$n \times \mu_p + z_{(0,95)} \times \sqrt{n} \times \sigma_p = CAP_{rep,10} - 0{,}16 \times n \times 15 \tag{6.5}$$

With:
$z_{(0,95)}$ = Standard normal distribution value for 0,95

Now, if the WIP level for some reason rises above n chances are larger than 5% that not all products are repaired within 10 days. The WIP level number includes warranty and out of warranty products.

The number of out of warranty repairs is not controlled in this research; still capacity is needed for these returns. Therefore in the WIP level room has to be made for out of warranty products. The amount of room can be determined from the analysis in chapter 4. We can relate the number of out of warranty repairs generated in 2006, according to the repairmen no large changes have taken place since 2006 and are not expected in the future, to the total number of returns and assess the needed capacity for out of warranty returns.

As followed from the analysis in chapter 4. Out of warranty returns accounted for 4 to 6,3% of the returns in the different months. The percentage of non-warranty returns repaired is 50,5%. This figure was quite robust over the year. Times needed for inspection are very small and can be neglected. The capacity needed for repairs not covered under warranty is dependent on the total number of returns. On average 5% * 50,5% = 2,5% of the total returns each week need to be repaired as out of warranty returns. In the different years on average between 300 and 400 returns arrive per week. We reserve capacity for 2,5% of 400, thus 10 products per week, as out of warranty returns. Therefore the WIP level of warranty returns needs to be kept under n-10 products.

6.3. Redesign 1: What to repair?: Profitability of repair

If capacity was unlimited and free it should be best to repair every product submitted under warranty if the transportation and part costs are neglected. However capacity is neither unlimited nor free. We can only repair part of the returns, but not all returns are equally interesting to repair. Therefore we need to establish a measure for the attractiveness of repairs. Now this is measured based on the cost price of a product and does not include other factors influencing the attractiveness of repair like, the time needed for repair and the spare part costs.

A new measure was developed. This measure is based on the costs and benefits of repair. For products within warranty the benefits of repair for RICOLEC are the avoided costs of replacement or reimbursement. The costs of repairing a product are a function of the spare parts used, the cost for transportation of the repaired product back to its submitter and the time necessary for repair. The attractiveness of repair depends on the repair time necessary since time is a scarce resource. Therefore the attractiveness of repair is expressed per unit of repair time. Mathematically the attractiveness of the repair of a specific failure type on a specific product type per unit of repair time can be defined as:

$$A_{ij} = \frac{Min(C_{reim,i}C_{repl,i}) - C_{ss,ij} - C_{tr,ki}}{t_{r,ij}} \tag{6.6}$$

With:
i = index indicating product type
j = index indicating error type
k = index indicating type of transport needed for a product from RICOLEC to the customer
A_{ij} = attractiveness of repair of a specific error on a specific product type per unit time
$t_{r,ij}$= average time necessary for the repair of a specific error type on a specific product type
$C_{reim,i}$ = cost for reimbursement for a specific product type
$C_{repl,j}$ = cost for replacement for a specific product type
$C_{ss,ij}$ = cost for spare parts for the repair of a specific error type on a specific product type
$C_{tr,ki}$ = cost of transportation of the product to the end user after repair for a specific product type transported by a specific type of transport.

The different variables are not all known at the moment due to data limitations. But all can either be gathered or measured by RICOLEC without great effort or cost. The time needed for repair of the product is unknown beforehand but can be estimated during the testing of the product which is done before a product is put on the market. This testing is done by an experienced technician. During the test he opens and closes the product and examines the structure of the components. Since the time needed for repair is predominantly determined by the time needed for opening and closing the product and the structure of components, he can estimate fairly accurately the time needed to perform a repair of a certain error. This is then done on product type error type combination level and therefore eliminates the variability between product types and/or error types. During the first repairs, if undertaken, the estimated time can be corrected.

The measure does not incorporate the probability that cannibalization is used nor the probability that repair fails. This because no product or product type specific information is present on these issues and using overall averages would not discriminate between results.

To be able to compute the profitability of repair level the error type needs to be known when the product arrives. The error type needs to be extracted from the complaint description given by the submitter. However, submitters do not always provide information and thus the type is not always known beforehand. If the error type is unknown the weighted average spare part costs and weighted average repair time for a product type can be used so the measure is still usable.

6.4. Redesign 1: Synthesis

When the WIP level on which it is 95% certain all products are repaired on time is known we can regulate the WIP level by influencing what is sent to the repair department for repair the WIP level around which the WIP is regulated is termed the WIP control level. Control can be done by setting the profitability of repair level at intake. Then if the WIP level is higher or lower than the control level the profitability of repair level at intake can be changed. However, due to the uncertainty in the arriving of products, the effect of a change in this level cannot be predicted beforehand. We only know that in general, if we raise the level fewer returns will be admitted and if we decrease the level more returns will be admitted. We have to observe the effect of the change and after observation, if necessary, adjust the level once more. The observation period has to be set. Since the returns are not distributed evenly over the week we propose to set the observation period on once a week to incorporate the variations in effect in the different days. Due to the unknown effect of the interventions the WIP level will vary a lot on the high and low side of the control level. Therefore, when the WIP level is controlled around the limit discussed above, a lot of products will not be repaired within the required times, rendering the repair useless, and the overall value of the within-time repairs will be low. By setting a lower WIP as control level the amount of products repaired late can be controlled.

By setting a lower control level the WIP, with the variation in arrivals, can be kept under the maximum level during the year, thus preventing products from being repaired too late. The downside of a lower WIP level is that the probability that repairmen are out of work increases and thus fewer repairs will be performed. Exactly what the influence is of lowering the level will be determined in the simulation.

6.5. Redesign 1b: Priority rules

Currently RICOLEC aims for a throughput time of 10 days for all products. However this target is not equally important for all products. If a product is not repaired within a certain amount of days the repair becomes useless in that still financial reimbursement needs to be paid to the submitter. For 70% of the products this period is 10 working days, whilst for 30% it equals 15 working days, although it is expected that the percentage of products requiring a throughput time of 10 days will increase in the future. The maximum throughput time is set by the submitter of the product and does not differ between products from the same submitter. This implicates that when a certain product is not repaired within 10 days it can better be a product that should be finished within 15 days since then the late repair does not lead to reimbursement costs. To influence this possibility priority can be given to certain products. To be able to do so batches of products should hold only either priority or non-priority products. Because priority products arrive with different logistic service providers than non priority products, this is easily arranged by the collection department.

Currently some priority at times is given to the 70% of products that need to be finished within 10 days, but it is unclear on which basis and under which circumstances this is done. We will therefore assess the influence of some priority rules. At RICOLEC, as explained, two groups of products can be discerned. The first group needs to be repaired within 10 days. For the second group this maximum is 15 days. A level of priority should also be assigned to out of warranty products since they need to be processed by the same repairmen. RICOLEC treats these repairs the same as non-priority warranty repairs. A throughput time of 10 working days thus is desirable, but 15 days is the maximum. Therefore it is logical to give out of warranty repairs the same priority as non-priority warranty products.

The goal of the priority rule is to make sure that the products that are not repaired within 10 working days are of the second group, provided the repair takes place within 15 working days. However due to the batches in which products are placed we can, without altering the manner of stock keeping, only assign priority to a batch of products. A batch contains products with the same intake date and the same maximum throughput time, thus with the same priority. We can therefore only prioritize products based on their entry date and maximum throughput time.

The used rules give some priority to certain products over other products. When priority is given to priority products they can upon entering 'skip the queue' a number of places to get in front of a number of non priority products. This increases the probability that they are repaired on time, but it decreases the probability that the skipped, non priority products, are repaired within 10 days. This since, as was explained in chapter 3, the average throughput time over all products will remain equal regardless of how many days priority is given to certain products. Therefore the total WIP needs to be controlled as well as was explained in 6.1.2. The effect of the priority rule in causing an increase in the percentage of product on time depends on the WIP level upon entering of a product and the number of days priority given to a product. However a first, small step to achieve higher performance on priority products can be obtained by a priority rule stating that priority products with a certain entry date are always repaired before non-priority products with the same entry date. Here thus a priority rule based on the entry date is used. This principle can be extended and priority can be varied in the number of days priority products get entry date priority over non-priority products. For example, priority products with an entry date of 20 April are repaired before non-priority products with an entry date of 19 April if priority products receive 1 day priority over non-priority products. In the simulation 1 and 5 days of priority are tested. 5 days priority leads to the same sequence as earliest Due Date scheduling since the difference in maximum throughput times between priority and non-priority products is 5 days. Earliest Due Date scheduling minimizes the maximal Due Date expiration and forms a starting point for the minimization of the number of orders with Due Date expiration (Bertrand *et al*, 1998) as was explained in chapter 3.

The effect of a priority rule is strongly dependent on the number of products receiving priority. This number is dependent on the number of returns from specific customers which cannot be controlled by RICOLEC. Therefore the effect of using a priority rule cannot be controlled by RICOLEC.

6.6. Redesign 1: Practical implications

To implement this redesign, both variants of it, no big structural, physical changes are needed. The decisions are made at the same points in time as in the current situation and the decision options also remain the same. The only changes made are in the basis for the decisions, thus in the data needed to make the decisions. We will discuss them in the order in which they were discussed above.

To regulate throughput time the amount of products in the WIP needs to be measured periodically. Also the link between the WIP level and the input level, as expressed in the profitability of repair, for the repair department has to be made explicit. Lastly a period to update the input level based on the WIP has to be set, preferably once a week.

To implement the selection of repairs based on the profitability information is needed on the expected spare part and transport costs in addition to the cost price also the return needs to be accompanied by a failure description from which the error type can be discerned. Lastly the time needed to repair the error is needed. All this information can be gathered from different sources including the sales department, the pre-market launch product test and the submitter. The sales price, that equals the cost for reimbursement, is known within RICOLEC, the repair time and spare part costs can be estimated from the pre-market launch test. The transport cost are determined by the manner of submitting the product and thus known upon arrival. Lastly RICOLEC needs to demand the accurate descriptions of the observed failures from their customers submitting the products, which might be difficult to realize. If a product is lacking a detailed failure description the average repair time and spare part costs for that product can be used for the calculation of the profitability of repair.

To implement the sequencing procedures for the products in the WIP only the stock keeping of the carts in the inventory should be altered to make sure repairmen can take the right cart. It should

7. Repair or not?, Redesign 2: Maximum WIP level extension

7.1. Redesign 2: Rationale

In the first redesign the WIP level needs to be controlled on a level below the 95% certainty WIP level at which timely repair is highly probable to prevent products from being too late. However, as stated, this may lead to fewer repairs. In order to increase the WIP level for control and limit the risk on useless repairs an upper limit on the WIP, a WIPcap, can be set as is done in CONWIP systems. This limit serves as a maximum on the WIP level, no more products are admitted when the maximum is reached.

7.2. Redesign 2: WIPlevel control with WIPcap

If a WIPcap is installed this has the following consequences for the admission of the products. If the WIPlevel is below the cap products are admitted as in the first scenario. If the limit is reached no products are sent to the repair department anymore. This contrasts the first redesign where products were admitted only based on profitability of repair which was set based on the WIP once a week allowing the WIP level to rise above the maximum. Now the WIP level for control can be set at any level, thus higher levels as in the first redesign, since the WIP level can never exceed the maximum level at which the cap is set. In this way more repairs can be performed. However, there is a drawback to this redesign. When the cap is reached no more products, thus also no more very lucrative products, will be sent for repair but instead less lucrative, already admitted products are repaired. This makes sure that, in hindsight, it is certain it would have been better to repair different products. The consequence of this error is higher when the WIP limit is closer to the control level for the WIP since then the cap will be reached more often.

The height of the cap can be set based on the probability that a newly arriving product is repaired late when the limit is reached following:

$$n \times \mu_p + z_{(0,95)} \times \sqrt{n} \times \sigma_p = CAP_{rep,x} - 0{,}16 \times n \times 15 \qquad (7.1)$$

We will use a probability of 95%.
We will examine the effect of different WIPcontrol levels with the WIPcap in the simulation.

7.3. Redesign 2: Practical implications

In addition to the first redesign now the height of the WIPlevel should be monitored at the intake of every new return, instead of once a week as in the first redesign, to examine when the WIPcap is reached. If the cap is reached it should be made sure no more products are sent for repair by the employees at intake.

8. Repair or not?, Redesign 3: Final decision at the repairman

In this redesign the decision whether to repair a product can be altered after intake. At intake a first decision is made and products are sent to the repair department. Then when a product is taken by a repairman, in contrast to the previous redesigns in which repair was always attempted on a send product, the final decision is made whether the product is repaired or not. Products can only be accessed in carts. The carts are processed in a first-come-first-served order.

8.1. Redesign 3: Rationale

Looking at the first two redesigns, both discussed options to control the timely repair of products have some drawbacks. These are mainly a consequence of the fact that the decision to repair has to be taken at intake and repair has to be performed when the decision is made. If the final decision to repair a product is postponed until the moment a product is taken by a repairman we can anticipate on this. Then if a product is either already too long in the WIP or if a product has a low profitability of repair and its repair would prevent the timely repair of another product it can be decided not to repair a product, so useless repairs can be avoided and it is controlled that the more expensive products are repaired. This decision is displayed to the repairmen when he looks up the repair in the system before repair. This redesign adds a control on the WIP to the first redesign. Below we will first discuss the WIP control mechanism in place in this redesign. Lastly the practical implications of the redesign are discussed.

8.2. Redesign 3: WIP control mechanism

In this redesign not all work in the queue has to be repaired. However if it does not have to be repaired it still needs to be handled. A repairman has to take the product, look up whether it should be repaired and place the product on the right shelf if it should not be repaired. It is estimated, based on the task description of a repair that this takes 5 minutes per product.

Because of the possibility to not repair a product even though it was sent to the repair department we have an extra control for the throughput time. If too much work is in the queue or the products have exceeded their maximum throughput time, some products are not repaired and the queue becomes shorter. The admittance of products to the repair department therefore becomes less influential, since variations in the WIP caused by the arrival process (that are only known in hindsight) can be corrected by not repairing products. However this correction still costs time, making the first selection needed.

Throughput time is regulated by setting a profitability of repair level at intake and a level at the repairmen. The level set at intake can be altered based on the WIP level. This level helps to regulate the admittance of products to the WIP. The level set at the repairmen also needs to be based on the amount of products in the WIP but serves to control the time within which the admitted repairs are processed, thus the flow out the WIP. Of the work in the queue the profitability of repair is known.

The average waiting time of a product when admitted to the repair department becomes, with first come first serve service:

$$n \times ((1 - PR) \times \mu_{np} + PR \times \mu_p) \tag{8.1}$$

With:
n = number of products in the queue
PR = part of products in the queue that is repaired ($0 \leq PR \leq 1$)
μ_{np} = average processing time for not-repaired products
μ_p = average processing time for a repair

In this formula n is influenced by the A_{ij} set at the product intake whilst PR is determined by the A_{ij} set at the repairmen and the probability a product has waited longer than its throughput time in the queue. By regulating both these levels we can control the waiting time and thus the throughput time of the repaired products.

8.2.1. Profitability of repair at intake

The profitability of repair at intake can be regulated around a control level for the WIP in the same manner as in the first redesign. This manner minimizes the expected deviations in the WIP, provided the assumed value distribution is correct. Although the time needed for products that exceeded their maximum stay is a lot shorter, 5 instead of 30 minutes on average, then in the previous redesign, still time is needed for the handling of a product. The amount of times this needs to be done limits the amount of repairs that can be done. This amount is related to the WIPlevel used for control as in redesign 1. In the simulation different levels for the control of the WIP are examined.

8.2.2. What to repair: profitability of repair at the repairmen

To control the throughput time of a product we can decide not to repair a product when the product is taken by a repairman. There are two reasons to decide not to repair a product after all. The first is that the product already has a throughput time larger then its maximum, rendering its repair useless. The second is that repairing a product can prevent, due to the time restrictions, the repair of another, more profitable, product.

For the first reason the control is simple, since it only depends on the throughput time of the product. If it is larger then the set maximum throughput time no repair should be undertaken.

For the second reason the profitability of repair of all products in the WIP and the total amount of products in the WIP is important. As long as the WIP level $n < N$ no products should not be repaired and thus A_{ij} at the repairmen should be 0. If $n > N$ then this is different and an extra selection needs to be made at the repairman.

If all products need to be repaired WIP should be kept under a certain level as in Redesign 1 and 2. This level can again be calculated by:

$$N \times \mu_p + z_{(0,95)} \times \sqrt{N} \times \sigma_p = CAP_{rep,x} - 0{,}16 \times N \times 15 \qquad (8.2)$$

Then if the number of products in the queue is larger than N some products in the queue should not be repaired to make sure the last admitted product has a high, 95%, chance of finishing on time. It can be that only late products should not be repaired. Therefore these need to be subtracted from the total. Then if more products should not be repaired, this number of products can be found by solving for PR:

$$(n-p) \times \left((1-PR) \times \mu_{np} + PR \times \mu_p\right) = N \times \mu_p \qquad (8.3)$$

With (in addition to above):
n = number of products in the WIP
p = number of late products in the WIP

Then knowing PR the number of products that should not be repaired but handled, h, from the WIP can be calculated by $(n-p) \times (1-PR) = h$. Now we can then select the profitability of repair such that h products in the WIP have a profitability lower than the selected level.

We assume that the standard deviation of the waiting time is equal to the standard deviation in redesign 1 and 2. This based on the fact that we will repair less products, which lowers the total standard deviation for the repaired products, but on the other hand we will not-repair more products, which adds to the standard deviation. Since both deviations are not known perfectly the effect on the total standard deviation can only be assumed. We assume the effect is zero.

8.3. Redesign 3: practical implications

In addition to the changes needed for the implementation of redesign 1 some extra changes need to be made in practice.

The addition of an extra decision with two options, repair or not, leads to a structural change in the process. The needed calculations can partly be performed based on the information also necessary for the first redesign. In addition it is necessary to monitor the products and their waiting times in the WIP, this needs to be monitored every time a product is added to or taken out of the WIP. The calculation of the waiting times can easily be done by subtracting the day of entry for the current day for all products in the WIP. The calculations have to be done every time a new product is taken by a repairman.

Practically a repairman needs to have a place where not repaired products can be stored. Furthermore it needs to be specified how these products are further processed and by whom. Lastly the repairmen and other involved personnel the new process should be explained so that they become confident in working with it.

9. Repair or not?, Redesign 4: Individual product scheduling

9.1. Redesign 4: Rationale

This redesign extends the previous redesigns by adding the possibility to determine the sequence of repair of products in the queue based on their individual characteristics instead of in batches with the same priority level and due date. In addition this order can be chosen after it is known which products have been sent for repair, this in contrast with the previous redesign where the order was determined by the batches and determined when a product was sent to the repair department.

In the previous redesigns a product is only not repaired if it either has a too low value or its waiting time is too high. The waiting time is not based on the value of a product so it can be that very expensive products are not given sufficient priority and thus exceed their maximum waiting time whilst cheap products do finish on time. Although the third redesign reduces this possibility, since it provides for the possibility of not-repairing cheaper items to make sure more expensive products are repaired it can still happen when the WIPlevel is large. This redesign prevents this from happening.

First the principle of individual product access and queue priority will be discussed. After this we will discuss the incorporation of individual access into redesigns 1and 3. In the second redesign WIP is always kept below the WIPcap rendering individual selection useless since all products can be repaired within the maximum throughput time. The discussed priority rule replaces the priority rules discussed within redesign 1 earlier.

9.2. WIP processing: Individual product access & priority

If we can select products to repair from the WIP based on their profitability of repair, we can choose to repair more profitable products before less-profitable products since this is more profitable. We could simply pick the product with the highest profitability of repair from the queue each time a repair is picked. However then it could be that products that are in the WIP for only just one day are picked before products already in the WIP for nine days. This might lead to suboptimal practices since a lot of products are not repaired within 10 working days whilst others are repaired the first day.

This problem can be overcome if the optimal sequence of repair for all products in the WIP is known so that the products that should be repaired next can be taken from stock. The optimal sequence however can be influenced by two parameters unknown beforehand. The first is that the sequence might be dependent on the products that will arrive within the time it takes to process the product scheduled for repair in the queue. However it is expected that this will only happen very rarely because of the considerable WIP already present at the repair department at any time. Therefore the probability that the optimal sequence for the period will change if the arrivals were known beforehand is very small and can be neglected. The second is that the time to process the scheduled products is unknown, whilst this time influences the time left for the other products and can thus influence their optimal sequence. It is not sure the products scheduled in a certain period are indeed repaired in the period, since processing times are variable. To make sure the repairmen have enough work the number of products taken from stock should be larger then the periods work. Left over products after the period can be used in the calculation of the next sequence again.

Because products are handled individually the handling time, which is needed to take the products from stock and place them in the right places after processing, can be specified per product. However handling time is unknown and dependent on the manner of stock keeping. If products are all easily accessible this figure will be low, if they are hard to reach it will be higher. In the first two redesigns, for the handling of the batches a total of 2 hours per day is used. When on average 34 repairs are carried out, which is the average number of repairs done in a day, this comes down to 3,5 minutes of handling time per product. This redesign, it is expected, can therefore only improve upon the previous redesigns if the handling times are lower or close to 3,5 minutes. Else the possible benefits obtained by repairing the right products are offset by the increase in handling time which leads to the repair of fewer products, provided the repairmen take the products from stock.

The optimal sequence of repair of the WIP is then dependent on the due date of each individual product and the revenues, which is the costs of financial reimbursement, which are made when a product is not repaired on time. Due dates should be set based on the maximum throughput time of a product.

The optimal schedule can then be found by adapting the algorithm of Hodgson-Moore described in the third chapter to the current situation. The incorporation of the algorithm in redesign 1 and redesign 3 is discussed below. It is uncertain an adaptation providing the optimal sequence for our specific problem situation can be made, as becomes evident from the discussion on this problem in chapter 3. In this report this will not be tried due to time limitations.

9.2.1. Redesign 4a: Incorporation of individual scheduling in redesign 1

In redesign 1 the value of the products that are not repaired on time is not controlled. By introducing the individual scheduling this can be regulated and minimized.
The Hodgson-Moore algorithm in its base form needs to be applied as follows:

1. All products need to be ranked according to their due date with the most recent due dates first.
2. For every product the start time should be determined based on the average repair time needed for the specific repair
3. If the starttime plus processtime of a product is smaller then its due date for all products this is the optimal sequence.
4. If a product is late it should be examined whether the least lucrative product, based on profitability of repair, with a larger processing time then the late product in the queue is less lucrative than the late product.
5. If such a product is present it should be taken out of the queue and placed after the late product.
6. Now repeat step 3 until all products are considered, products that are already placed backwards are not considered.

This algorithm does not provide an optimal sequence in our situation since the assumptions, eg. equal weights for products, discussed in chapter 3 are not met. However it is expected that an adaptation of this algorithm can be made that can be used as a heuristic to find close to optimal sequences for the situation under study.

The adapted algorithm should be used to calculate the optimal sequence once a day due to the time consuming calculations that limit the use of calculation of the optimal sequence before each repair. Then the products that come first in the sequence are taken from stock. The repairmen on average repair the products scheduled for one day, and therefore should take a certain amount of products from stock. However to prevent them, when they work faster, from being out of work, we should take more products then the products scheduled for that day. Since we assumed the repair times for the products to be normal distributed with an overall mean of 30 minutes and a standard deviation of 5 minutes, we can determine how large the probability is that a number of average products is repaired in a day. To be 95 % sure that the repairmen will not finish all products taken from stock in one day we need to determine the number of products taken from stock. This can be done by solving for the number of products:

$$n \times 30 - z_{(0,95)} \times \sqrt{n} \times 5 + n \times t_h = CAP_{rep,1} - 0{,}16 \times n \times 15 \qquad (9.1)$$

In which:
n = the number of products
$z_{(0,95)}$ = standard normal distribution value for 0,95
$CAP_{rep,1}$ = capacity the coming day
t_h = time needed to take one product from stock

Then the first n products of the calculated sequence need to be taken from stock and be repaired in order of the optimal sequence. If not all taken products are repaired the left over products do not have to be placed back in stock, until it is certain they are not in the first n products of the optimal sequence the next day. This to prevent the unnecessary handling of products.

9.2.3. Redesign 4b: Incorporation of individual scheduling in redesign 3

In redesign 3 the processing of products beyond their due date is partly regulated by the level at the repairmen. However this only functions if the WIP is kept within certain range of the limit. To prevent lucrative products from being late when WIP is outside this range, individual access can be of use. The procedure to be developed should be applied analogous to the procedure discussed for the first redesign in 9.2.2. The only difference is that products that are late or of which the profitability level is to low are not repaired and their claims are settled by the collection department. The possibility that on time products are not repaired influences the number of products that need to be taken out of stock in the beginning of the day. Still $n \times 30$ minutes should be taken from stock, however products that will be handled need to count for 5 minutes of work instead of their processing time. It is known how many products will be handled, so the number of products taken from stock can be adjusted to make sure $n \times 30$ minutes of work for the repairmen are taken from stock. Another option that can be looked into is to only take products from stock that need to be repaired. Products that need to be handled because they have exceeded their stay can then be handled by other employees, eg employees from the collection department. This creates more capacity for repair.

9.2.4. Comparison models and priority rules

Although the above stated modeling of priority among products is comprehensive and is expected to lead to close to optimal results with respect to the selection of enough and the right products for repair, it is questionable how much better it performs compared with the previous redesigns. The fourth redesign however cannot be simulated like the other three redesigns, since the redesign first needs to be developed. The expectation is that the decision procedures for this redesign in the form of a model can be developed and implemented however the development and implementation is not done in this project due to time limitations. Now if the expected benefits are large, RICOLEC can choose to develop the model. We will assess the possible impact based on the upper boundaries on performance and the performance of the previous redesigns.

9.3. Redesign 4: practical implications

To implement this redesign in addition to the changes needed for the first/third redesign, the manner of stock keeping at RICOLEC needs to be drastically changed. All products need to be made accessible individually. Then a placement system needs to be developed so it is known where products are in stock so that they can be retrieved easily. The products have to be placed in the stock by the employees that take the products in and be retrieved by the repairmen or other personnel before repair.

Besides this it is necessary to continuously keep up to date information on the products in stock, since this is necessary to calculate the optimal sequence.

One increase in risk inherent in the individual handling of products needs to be mentioned as well. Individual product handling increases the risk of product damage since it is much easier to drop an individual product than a full cart.

10. Testing products

10.1. Why testing products

Ideally you would have full knowledge on the performance of all the products you have sold, since this knowledge can be useful in the development or purchase of new products Thus, if this knowledge was obtainable at no costs, you would like to know what the failures on all incoming products were so that full knowledge on the failures can be reported to your supplier and used to prevent problems later. For products that are repaired registration of the error is 'free' because repair, which incorporates the actions taken during testing, is undertaken. However for products that are not repaired this knowledge is not free since tests have to be performed to gain it, these tests are estimated by the repairmen based on their knowledge of the products to take 15 minutes per product on average. However by sampling the returned products knowledge can be gathered on the failure behavior of the product types without testing all products. The more products are sampled, the more precise the obtained knowledge is.

RICOLEC wants to filter out the dominant failures for each series of each product type. A series constitutes an order of a certain product type at a supplier, a series accounts for between 100 and 2000 products. RICOLEC expects the failures to be dependent on the series, since different series are manufactured on different times with possibly different quality, and therefore wants to test on series level Upon return it is known to RICOLEC from which series a product is. The occuring failures need to be classified during the testing of returned products.

The testing is done on IRIS code level. The section code and defect code should be combined into one result. The test thus leads to one classification for the failure section and defect code together.

10.2. How many products to test

When 2 or more tests are performed, we can calculate boundaries for the probability that a specific failure type, thus a specific combination of a section and defect code, occurs. The lower boundary states that the probability is not lower then a certain figure and the upper boundary states it is not higher then a certain figure, both with some confidence. Therefore to set the boundaries a confidence level, α, needs to be specified by RICOLEC. The lower boundary of the probability, p_{min}, is then calculated with:

$$z_\alpha = \frac{x - n \times p_{min}}{\sqrt{n \times p_{min} \times (1 - p_{min})}} \tag{10.1}$$

With:
z_α = Standard normal distribution value for confidence level α
x = number of occurrences of section-defect code combination in the tested products
n = total tests performed on specific product series up till now
p_{min} = minimal probability on the occurrence of a specific section-defect code combination for the product series

The upper boundary, p_{max}, is then calculated with:

$$-z_\alpha = \frac{x - n \times p_{max}}{\sqrt{n \times p_{max} \times (1 - p_{max})}} \tag{10.2}$$

With (in addition to above):
p_{max} = maximum probability on the occurrence of a specific section-defect code combination for the product series.

Since the tests are done on different products the tests are mutually independent, which is prerequisite for using the normal distribution.

Now the more products are sampled, thus the larger n, the smaller the difference between p_{max} and p_{min} becomes and thus the more precise the knowledge on the probability on a specific failure type becomes. RICOLEC now has to specify a degree of precision expressed as an interval of width $p_{max} - p_{min}$. This interval can be calculated after every test and the sampling can stop when the specified precision is reached. However to avoid for the possibility of endless testing because the degree of precision is never reached, a maximum on the number of tests needs to specified as well.

To give an indication, using a confidence level of 85% and an interval width of 0,20 the interval width is reached after 20 to 30 tests depending on the probability of occurrence of the failure type.

Because it is desirable to have the information of the failures as quickly as possible the tests should be performed on the first returns of the product despite the fact that this is not a random sample, which is desired (Cooper and Schindler, 2003). This since some failures might be overrepresented in the first returns, because they generally occur shortly after purchase (e.g. users having problems installing the product and sending it as failure because of this).

10.3. Capacity needed for testing

In order to get an idea of the amount of time needed for testing products each week we have calculated a rough estimate of the number of tests needed each month. The estimation of the number of tests should be done on a week-level. Unfortunately the necessary information was only available on month level. An estimate of the number of tests required in each month was determined by filtering out all product types the types for which less than ten returns, to account for overestimation, were received until the beginning of 2006. For these types the first twenty returns in 2006 were determined. This led to an indication of the number of tests that should have been done in 2006. This estimate was based on the number of twenty tests per product type, which is probably slightly lower then the number of tests needed per product series. Totally 934 tests (including during repair) should have been needed, with a minimum of 56 and a maximum 141 tests per month. This figure probably underestimates the number of tests needed since it does not incorporate multiple series per product type, whilst testing needs to occur on series level. Comparison of the number of tests needed in each month and the total number of returns showed no constant relation. Therefore we cannot accurately predict the number of tests needed based on the number of returns received.

The time needed for inspection is determined by the depth of failure analysis desired by RICOLEC. The desire is to classify the failure section and the defect mode. The time needed for this is a subset of the time needed for the repair of a product since it involves the same steps. The product has to be connected and the complaint needs to be checked. Than, in most cases, the repair man needs to open the product to establish the failing component and the defect. Lastly he should close the product again. As stated, it is estimated that on average 15 minutes are needed to perform a test on a product.

Therefore, since only a limited number of products need to be tested, 934 out of 21000, with an average time per test of 15 minutes, the total time needed for testing lies around 234 hours per year. This figure includes the tests done during repair on products that are repaired, but underestimates the number of tests as indicated above. It therefore is not necessary to be able to predict the number of tests necessary each week. RICOLEC will have one employee perform the tests as part of his task description. This employee does not repair products.

11. Cannibalize & replace/reimburse

11.1. Stock to cannibalize or sell second hand?

For all warranty products that are not repaired a decision has to be made whether the product should be put on stock for cannibalization or sold second hand. The products for which this is needed can be divided into two groups. The first group is the products that are not repaired because there profitability level is not high enough. The second group consists of the products that are not repaired because of product specific causes, with the dominant cause being that a product is a Death On Arrival (DOA), which are as stated in chapter 2 never repaired. The second group as a consequence partly consists of products that have a high profitability of repair level.

For the products with a high profitability of repair level in the second group the chance that a product will be of use to obtain parts is high since similar products, with a high profitability of repair, are sent for repair to the department. Therefore this group of products should be stocked for cannibalization.

In the first group are a lot of product types that are never repaired by the repair department. These products are therefore of no use for parts and should always be sold second hand. However introducing a profitability of repair level upon acceptance as proposed in chapters 6 to 9, this level will fluctuate based on the WIP. Because of this fluctuating profitability of repair level used in the different weeks there are products that are sent for repair in one week, but not in other weeks. These products, when not sent for repair should be kept for cannibalization. To be able to define these products a lower limit on the profitability of repair used for cannibalization should be implemented.

As stated in chapter 3 (e.g. Van der Laan *et al,* 1996 ; Inderfurth, 1997) a lot of specific data is needed to design an optimal cannibalization policy. This data is not and will not be available at RICOLEC and therefore an exact determination of the optimal level is impossible. Besides, Inderfurth (1997) shows that in the case of large difference between procurement and cannibalization leadtimes, as is the case in the discussed situation, since new parts have to be bought from suppliers all over the world, the control rules become even more difficult.

Now creating a policy with the available information a simple heuristic based on a profitability of repair level, the same measure used to determine whether to repair a product, is made. We know that if the set profitability of repair level is too low, too much will be stocked and the stock needs to be cleaned from unusable products more often and if the set level is too high, products with useful parts are sold secondhand more often. The option chosen here is to set the level as a moving minimum based on the used profitability of repair levels in the last three months, equaling 13 weeks. Three months was chosen to include large variations in the profitability of repair level over time. Thus:

$$A_{can,t} = \min(A_{ij,t-1}, A_{ij,t-2}, \ldots, A_{ij,t-13}) \qquad (11.1)$$

In which:
t = index indicating time in weeks
$A_{can,t}$ = the profitability of repair level used for stocking for cannibalization in week t
$A_{ij,t}$ = profitability of repair level (as specified in formula 6.6) used in week t

Practice will show whether this simple heuristic suffices and a right balance is found between stocking products and selling them second hand. It is of course quite simple to change the heuristic or time periods used. A situation where the used profitability for repair decreases over time to the lowest levels used for instance can cause valuable products to be sold secondhand.

We do not know the demand for parts from cannibalization, certainly not on the part specific level. Therefore we cannot calculate the inventory position of the cannibalization stock or judge adequately whether the stock is full or not. We can not determine when products need to be deleted from the cannibalization stock because they are obsolete and can better be sold secondhand. The repair men have to do this based on their expertise on a regular basis.

11.2. Replace or reimburse?

The decision whether to settle a claim by replacement or by financial reimbursement involves more than only financial motives. The non-financial motive for replacement is that a product is distributed and the brands and products are more visible to the customer, which might have a positive effect on the reputation and might lead to higher brand recognition.

From a practical point of view replacement is more difficult than reimbursement. Replacement requires a product of the same type or a similar type also accepted by the customer to be available on stock. However most customers do not accept alternatives because the alternatives are not known in their systems and RICOLEC does not keep stock of product types to serve as replacement products. Concluding, it is often not possible to replace a product because of reasons out of our control and we can only give an indication of the ideal best situation. Lastly some customers have very specific preferences for replacement or reimbursement, which RICOLEC wants to fulfill.

In our model we will simply compare the cost related to replacement with the cost of reimbursement, whichever is the lowest is the preferred option. We are aware of the discrepancy that will result here between model prescription and real world action, which means that the indicated best option might not be best considering non-financial motives or not realizable considering stock positions and therefore the prescribed option by the model should/can not always be followed.

The cost for reimbursement simply consists of the price the customer has bought the product for. The cost for replacement consists of the costprice of the newly distributed product and its distribution costs. In mathematical terms this yields:

Replace if: $C_{repl} < C_{reim}$
Reimburse if: $C_{repl} > C_{reim}$
With: $C_{repl} = C_{cpr} + C_{tr}$

Where:
C_{cpr} = cost price of the product
C_{repl} = replacement costs for the product
C_{reim} = reimbursement costs for the product
C_{tr} = transportation costs for the product

12. Simulation of the repair process

In this chapter we will simulate the repair process to evaluate the performance of the redesigns made in chapters 6 to 8. In the simulation we want to evaluate the performance of the different redesigns. First we will simulate the first redesign, with and without the extension of the priority rules. Both redesign 2 and 3 are extensions of the first redesign that provide for extra control against useless repairs without lowering the WIPlevel for control. Therefore we will simulate these redesigns for the scenarios where useless repairs can not be avoided, or when the first redesign is not attractive due to other reasons, the other two redesigns are tested. The evaluations are performed in a simulated repair context similar to the context at RICOLEC.

The simulation will be conducted in two stages. The first stage involves the simulation of the first redesign with and without the priority rule. In the second stage the other two redesigns will be evaluated.

In the simulations we will vary a number of parameters in our model. First we will define which parameters we will vary. After this the not-considered parameters and the performance criteria will be discussed. Finally the simulation engine and simulation settings will be discussed, after which all simulations will be carried out. The simulation results will be compared and discussed in the results section in chapters 13 to 16.

12.1. Parameters of interest

The parameters that are varied are discussed below. The WIP level around which the number of products is controlled was varied within this context. First for all three redesigns the influence of the WIP level used for control in the present situation is examined. Then to determine how variations in settings and the control WIP level influence the performance of the first redesign different scenarios were evaluated at different control WIP levels. The same WIP levels were then used to evaluate Redesign 2 and 3. These WIP levels were based on the results on the influence of the WIP level for control from the first simulations of redesign 1 and are 30, 40, 60, 80, 100 and 130 products.

12.1.1. The number of returns per year

It is expected by RICOLEC that the distribution of the returns in a week and over the year does not change in the coming years. However it is unknown how many returns will be submitted in the future. This depends both on the quality of newly sold products and the amount of products sold. To see how the redesigns function when the overall number of returns decreases or increases, the number of returns per year is varied on three levels being 15000, 20000, and 30000 products per year. These figures are based on the return levels from 2005 to 2007. The variation in the distribution of the returns per day, not incorporating the variation caused by the yearly seasonal effects and the known variation in the week due to logistic service provider delivery schedules, have been rather constant over the last years. In all years it is adequately represented by a normal distribution with a standard deviation of 30 products. The average of this distribution is then varied to create the different levels of 15000, 20000 and 30000 products. In the simulation the day and seasonal variations are included. The seasonality is approximated by periods of 4 weeks each having their own seasonality factor, being the average seasonality factor extracted from the returns in 2005 to 2007, as explained in chapter 4.

12.1.2. The value distribution of the returns

Although it is expected by RICOLEC that the value distribution of the products remains constant over time, still changes in its influence are examined because changes in the value distribution can have effects on the maximum value of products that are repaired and on the performance of the redesigns.

The products can be divided into 5 groups based on the reimbursement price that needs to be paid to the retailers when a product is not repaired. All groups constitute a different part of the total products and consist of different product groups, although some overlap can be observed:

1. €0<Price < €25, 15% of the products. Product groups: discman, radio, alarmclock
2. €25<Price<€50, 30 % of the products. Groups: DVD, Audiosets, Portable Radio/CD

amount of days and within the set throughput time maximum. This also shows the percentage of products repaired within time and within the desired number of days. The second is the value of the products that are repaired.

12.4. Simulation engine and created models

The simulation models for the different redesigns and parameters were constructed in CPNTools using Coloured Petri Net language. Coloured Petri Nets are an extension of ordinary Petri Nets. Petri Nets are a widely used modeling tool that graphically depicts the structure of a model, which makes the model insightful. The Coloured Petri Nets language extends ordinary Petri Nets with the ability to model time and information (Van der Aalst, 2003). The simulations were run in CPNTools which is a program supporting Coloured Petri Net modeling. The models for each redesign can be found in Appendix 12 along with a short description of the symbols used.

To be clear, the models in Appendix 12 display the decision procedures used in the different redesigns for the decision whether to repair or not. They only relate to the repair or not? decision as indicated in the redesigned flow model in figure 5.1. and not to any of the other decisions in that figure. They display the decision procedures underlying the repair or not? decision, and should not be confused with the flow model in figure 5.1 nor taken for elaborations of this whole flow model.

12.5. Model validation

The created models were validated along two lines. Firstly the models were checked on correctness, meaning that every one case going in the model also came out as one case. This was done with a state space analysis. To be able to conduct the state space analysis the models were slightly simplified, however the results also hold for the used models. The results showed that the models are sound and that they therefore display the intended redesigns correctly from a decision structure point of view, meaning that the model resembles the proposed course of action.

The created models were also checked on validity from an academic perspective, meaning the results were checked for feasibility. To do so the maximum throughput time were varied between 1 and 265 working days (1 year) to examine whether the total value of repaired products remained below the maximal attainable value. This value is calculated and explained in section 13.1. The simulation results were feasible, the maximum value was never exceeded significantly and the results for a throughput time of one day were significantly lower as for a throughput time of 265 working days as can be expected since short times leave no room for buffering uncertainty in the WIP.

12.6. Simulation settings

12.6.1. Replications & simulation length

For the different redesigns and circumstances simulations were performed. For each set of circumstances described above 10 replications were performed, each with independent arrival processes. 10 was chosen to obtain accurate, fairly small confidence intervals which can then be used to compare the value of the repairs. Therefore this number is well above the rule of thumb of 5 replications advocated in Goossenaerts and Pels (2005). The time needed per simulation varies between redesigns and scenarios between 5 and 25 minutes. Each replication covered the simulation of the start up period plus one year for observation. In each replication one year was thus observed. This was done because this period includes all seasonal variation in the arrival process and the performance of the redesigns can be judged appropriately since the variation in a year can influence the redesigns performance.

12.6.2 Warm up & cool down periods

Due to the empty system in which the first product of a simulation run arrives, no WIP is in the system, their performance deviates from the cases later in the run. The throughput time of these first products will be low due to the absence of waiting time. To eliminate this effect a start up period was implemented during which no measurement is undertaken. During this start up period all cases are sent for repair, to create a WIP level close to the WIP control level. The start up period length is determined by the number of cases that arrive on average and the WIP level on which the redesign should be controlled. The fewer cases arrive in a simulation setting, the longer the required start-up period, the lower the WIP level for control, the shorter the start-up period. In general the necessary start up period varies between 2 and 4 weeks. To be sure no start-up effects are incorporated we used start-up periods 2 weeks longer than strictly needed, thus the used start-up periods varied between 4 and 6 weeks. The monitors measuring the performance of the redesign were programmed to start monitoring after the start-up period finished.

No cool down effect is observed in the repair department. This because the result of a product are mainly dependent on the throughput time of products in front of them and this in the end of a simulation run is similar to in the middle of a simulation run, therefore the monitors are not adjusted to incorporate a cool down period.

13. Design 1 to 3: results & conclusion

We will discuss the results from the simulation and calculations as follows. First we will calculate upper levels for the attainable total value of repaired products for the different scenarios tested in the simulation. After this we will discuss the results of the simulation of the first redesign and the influence of the priority rule in this redesign. Then the performance of redesign 2 and 3 will be discussed separately after which we will form a conclusion on the functioning of these redesigns. Then in the subsequent chapters we will first discuss the performance of the redesigns under 1 day maximum throughput times in chapter 14. Then the performance under a decreased capacity will be discussed in chapter 15 and in chapter 16, lastly, we will discuss whether it can be beneficial to implement the fourth redesign under different times needed for handling.

13.1. Maximal performance: an upper boundary

Since capacity and the number, processing times and the value of the arrivals are known we can, not taking into account the maximum throughput times of products, construct upper boundaries for the different scenarios. This calculation resembles a situation in which all products arrive in the first day of the year and need to be handled by the first day of the next year. We can then extract the most lucrative product for repair from stock every time we pick one. If we then assume processing times to be constants on the mean level of the distribution we can calculate an upper boundary for each scenario, by picking the most lucrative until the year is finished. The resulting upper boundaries are depicted in table 13.1. In the table the time needed for handling and out of warranty repairs is subtracted from the total capacity, this table can serve to evaluate the performances of the first three redesigns.

		15000	20000	30000
normal value distribution, normal processing times		1634430	2001487	2637870
high value distribution, normal processing times		2513820	3108870	4171671
low value distribution, normal processing times		1036685	1262660	1615420
normal value distribution, low processing times		1705242	2111312	2777808

Table 13.1: Upper boundaries for the different scenarios with handling by repairmen, values in €

13.2. Redesign 1

We will first discuss the performance of the first redesign. The results of the Redesign without the priority rule and with the priority rule are discussed separately.

In the first redesign the uncertainty in the arrivals is buffered in the WIP level around which the WIP is controlled. Control is performed in hindsight, therefore variations above and below the WIP level occur. If these variations lead to a temporary WIP level of zero, the repairmen are out of work. If these variations lead to a temporarily too high WIP level the repairmen perform useless repairs. First the influence of the WIP control level for the situation with 20000 returns, a normal value distribution, normal processing times and a 10 day maximum throughput time was examined. The highest attained value is €1946540 at a WIPlevel of 100 products. The attained values with WIP levels between 50 and 140 do not deviate significantly (90% level) from this level. At WIPlevels above 140 useless repairs limit the attained value, at levels below 50 repairmen are out of work frequently which limits the total value. After this the performance of this WIP range was examined for the other combinations, zero, one and five day priority, and the different maximum throughput times for control of the WIP on levels of 130, 100, 80, 60, 40 and 30.

We will focus on the total value of the products that were repaired within their maximum throughput time and the highest WIPlevels above which this value decreases because of useless repairs. We will also examine for each scenario from below which WIPlevel the number of repairs significantly decreases because repairmen are often out of work.

13.2.1.Redesign 1: FCFS repair

The performance attained by the first redesign is very high. For almost all different scenarios a close to optimal value can be attained. More specifically, we can distinguish the performance based on the maximum throughput time for priority products. We observe that the WIPlevel above which the attained value significantly decreases with the number of days of throughput time. The level increases as the repair times decrease, because more products can be repaired in the same time. This can be seen in Table 13.2. The table displays the WIPlevel and the highest attained value with a WIP level lower than the indicated level. The bolt printed values indicated that these values are significantly (90% level) smaller than the maximum values attained when the desired throughput time is longer. Graphs displaying the results for the total value for the different scenarios at different WIP levels can be found in Appendix 13.1.1. The figures in the appendix show that the total sales value of the repaired products are dependent of the used control level. The control level with the highest value increases with the maximum throughput time.

Nr of days maximum	15000		20000		30000	
normal value distribution, normal processing times	WIPlevel	Total value	WIPlevel	Total value	WIPlevel	Total value
4	60	1593477	60	1934320	40	2535433
6	80	1605627	80	1934320	80	2543570
8	100	1605627	100	1943256	100	2543570
10	130	1605627	130	1943256	130	2543570
high value distribution normal processing times						
nr of days maximum	15000		20000		30000	
4	60	2389560	40	2949410	40	**3853746**
6	80	2398594	80	2949410	60	3924439
8	100	2395494	100	2965243	80	3956157
10	130	2395547	130	2988105	100	3975385
low value distribution, normal processing times						
nr of days maximum	15000		20000		30000	
4	60	1019153	40	1215482	40	**1563518**
6	80	1030621	80	1232399	80	1590672
8	100	1031390	100	1232760	100	1596652
10	130	1031390	130	1232760	100	1596652
normal value distribution, low processing times						
nr of days maximum	15000		20000		30000	
4	80	**1665374**	60	2038934	80	2688051
6	80	1692301	80	2061024	80	2693242
8	100	1692301	100	2061024	100	2705433
10	100	1692301	130	2061024	130	2705511

Table 13.2: maximum WIP level with performance maximum

The risk that repairmen do not have enough work and thus repair less products on the other hand becomes significantly (90% level) apparent in the redesigns at low WIP levels. The different levels are displayed in table 13.3. Graps indicating the number of products repaired at each WIPlevel are displayed in Appendix 13.1.2. The figures display that the number of repaired products increases with the WIP level used for control.

Scenario\number of returns:	15000	20000	30000
Normal value distribution, normal processing times	60	40	40
High value distribution, normal processing times	30	40	30
Low value distribution, normal processing times	40	40	40
Normal value distribution, low processing times	60	40	40

Table 13.3: WIPlevels from which on the number of repairs decreases

Combining the results from the two tables we can construct intervals for the WIP level for which the redesign attains its highest value. These are displayed in Table 13.4.

Nr of days maximum	15000	20000	30000
normal value distribution, normal processing times	WIPlevel interval	WIPlevel interval	WIPlevel interval
4	60 - 60	40 - 60	40 - 40
6	60 - 80	40 - 80	40 - 80
8	60 - 100	40 - 100	40 - 100
10	60 - >130	40 - >130	40 - >130
high value distribution normal processing times			
nr of days maximum	15000	20000	30000
4	30 - 60	40 - 40	30 - 40
6	30 - 80	40 - 80	30 - 60
8	30 - 100	40 - 100	30 - 80
10	30 - >130	40 - >130	30 - 100
low value distribution, normal processing times			
nr of days maximum	15000	20000	30000
4	40 - 60	40 - 40	40 - 40
6	40 - 80	40 - 80	40 - 80
8	40 - 100	40 - 100	40 - 100
10	40 - >130	40 - >130	40 - 100
normal value distribution, low processing times			
nr of days maximum	15000	20000	30000
4	60 - 80	40 - 60	40 - 80
6	60 - 80	40 - 80	40 - 80
8	60 - 100	40 - 100	40 - 100
10	60 - 100	40 - >130	40 - >130

Table 13.4: WIPlevel intervals for the total value of repairs

The intervals vary in size, with some having the same upper and lower limit. A complicating factor is that both the value distribution and the number of returns are unknown beforehand. Then to make sure the highest possible value of repairs is attained the highest lower limit and lowest upper limit from the above scenarios needs to be taken. This leads to the aggregate intervals for the different maximum throughput times displayed in Table 13.5. Now if the maximum throughput time is four days we cannot set a WIPlevel and be confident the maximum attainable value is reached.

Maximum throughput time	WIPlevel interval
4	60 - 40
6	60 - 60
8	60 - 80
10	60 - 100

Table 13.5. Aggregate WIPlevel intervals

13.2.2. Redesign 1: Performance of redesign 1 with a priority rule

To evaluate the performance of the priority rule we will look at the percentage of products repaired late and within the desired throughput time for all scenarios. If the percentage of products repaired late decreases the total value of the repairs increases. Appendix 13.1.3 shows tables for each scenario indicating the different percentages of products late and within desired time when 70 and 90% are priority products. As can be seen the effect of the priority rule varies, the percentage of products repaired late decreases, causing a higher total value of the repairs in all situations where products are repaired late on occasion. The increase in value is dependent on the probability that products are repaired late without the priority rule. The dependency can be seen in Table 13.6, which is an aggregation of the tables in Appendix 13.1.3. The table displays the average decrease in products repaired late caused by the priority rule for different intervals of late products.

	Decrease in % late products:	
No Priority	1 day	5 days
0-10%	1.1%	1.5%
11-20%	2.7%	4.5%
21-30%	2.1%	4.9%
>30%	1.5%	3.0%

Table 13.6: Decrease in late products for 90% priority products

We see that the largest increases are observed for the 5 day priority rule. The effect is largest when between 11 and 30% of the products are repaired late without priority rule. When the total value of repairs is already (close) to its highest level without priority, thus when only a small percentage of products are late, the priority rule adds less value and when the probability becomes larger then 30% the effect decreases. The added value is dependent on the value distribution and number of returns per year.

On the other hand the percentage of products repaired within the desired throughput time varies from the situation with no priority rule. The effect is shown in Table 13.7.

	Decrease in % within the desired throughput time	
No priority	1day	5 days
91-100%	0.6%	5.1%
81- 90%	0.6%	0.6%
71-80%	0.2%	-1.3%
<70%	-0.1%	-3.2%

Table 13.7. Decrease in products repaired within the desired maximum for 90% priority products

Again we see the effect is stronger when 5 days priority is given. The effect is largest when more than 90% of the products are repaired on time, when the redesign without priority is functioning rather well. A positive effect is that when a low percentage (<70% for 1 day, <80% for 5 days) of the products are repaired within the desired time this percentage can be increased by using the priority rule.

Concluding we can state that when the performance of redesign 1 is not optimal, the total value of repairs can be increased slightly. The closer to the maximum value redesign 1 becomes, the smaller the influence of the priority rule becomes and the bigger the decrease in products not repaired within the desired throughput time becomes. If the performance of the redesign is far from optimal, e.g. a large percentage of products are repaired late, the priority rule improves performance, but its implementation does not lead to the attainment of the maximum value of repairs.

13.3. Redesign 2

Redesign 2 solves the dilemma involving of either fewer repairs or too late repairs differently and therefore might lead to better results with respect to the WIPlevel intervals than the first redesign. However, if the risk that products are repaired late is negligible in the first redesign, the second redesign becomes equal to the first. We have simulated redesign 2 for the scenarios where this probability was not negligible. First we shortly show that the redesign in the other scenarios, does not add significantly to the first redesign.

In the simulation the WIPcap was set at 310 products for the 10 day maximum throughput scenario. For the 8, 6 and 4 days the cap was set at 247, 185 and 123 respectively, based on formula 7.1. The level at which the WIP is controlled should influence the percentage of time the WIP is full and thus the amount of lucrative products not repaired. For this redesign the range for the WIPlevel giving the highest value was searched for the situation with 20000 returns, normal processing times and the normal value distribution, and 10 days throughput time for the priority products. The total value of repairs was €1953568,-, which was attained at a WIPlevel of 230 products. The values attained with WIPlevels between 50 and 260 product did not differ significantly from this value. The optimal value does not deviate significantly from the value obtained with redesign 1. However the WIP level becomes less important indicated by the wide range with which close to optimal values are attained.

The total value of the repairs and the range for the WIPlevel for the different scenarios are displayed in table 13.8. The lower boundary of the range is equal to the boundary in the first redesign. Appendix 13.2 displays graphs with the relation between WIPlevel and attained value for the simulated scenarios and levels. The figures in the appendix show the dependency of the total sales value of the repairs on the WIPlevel used for control. Higher WIPlevels for control lead to lower total sales values, however the relation is not as explicit as for the first design.

Returns per year:		15000		20000		30000	
Nr of days maximum		WIPlevel	Total value	WIPlevel	Total value	WIPlevel	Total value
normal value distribution, normal processing times							
	4	60 - 80	1592658	40 - 80	1937636	40 - 80	2540334
	6	60 - >130	1588940	40 - >130	1947758	40 - >130	2542487
	8	60 - >130	1582044	40 - >130	1943189	40 - >130	2548374
high value distribution normal processing times							
	4	30 - 80	2399574	40 - 80	2953155	30 - 80	3938075
	6	30 - 100	2404035	40 - 100	2955323	30 - 100	3954308
	8	30 - 100	2400719	40 - 100	2970646	30 - >130	3921159
	10					30 - >130	3939764
low value distribution, normal processing times							
	4	40 - 100	1023202	40 - 80	1232386	40 - 80	1587945
	6	40 - >130	1023745	40 - >130	1228581	40 - >130	1585701
	8	40 - >130	1022599	40 - >100	1235332	40 - >130	1584351
	10					40- >130	1576205
normal value distribution, low processing times							
	4	60 - 80	1682207	40 - 80	2059737	40 - 80	2690026
	6	60 - 100	1676008	40 - >130	2049340	40 - >130	2704752
	8	60 - 100	1642817	40 - >130	2023734	40 - >130	2706194
	10	60 - >130	1660148				

Table 13.8: Total value of repairs and WIPlevel intervals for Redesign 2, values in €

The total values of repairs for most scenarios are not significantly lower or higher than for the first redesign. The WIPlevel intervals for which they are attained however are wider then for the first redesign. Also, for the three scenarios in which significant lower values were attained in Redesign 1, this redesign performs significantly better. The upper boundary WIPlevels are above the WIPlevels from below which the number of repairs decreases. Therefore the intervals with unknown arrivals and value distribution are all positive in size, as can be seen in table 13.9.

Maximum throughput time	WIPlevel interval
4	60 - 80
6	60 - 100
8	60 - 100
10	60 - >130

Table 13.9.: Aggregate WIPlevel intervals for redesign 2

13.4. Redesign 3

The third redesign reduces the influence of products that are in the WIP too long. Next to that it makes sure the right products are handled and repaired by an extra level of profitability at the repairmen. However when there is a negligible risk on products being in the WIP too long this redesign is equal to the first redesign.

Table 13.10 displays the WIPlevel intervals and the attained maximum value for the simulated scenarios. Again the lower limits are equal to the first redesign. Appendix 13.3 displays the graphs indicating the relation between WIPlevel and the attained total value. Again the dependency of the total sales value on the WIPlevel for control is shown. In the figures the total sales value is largely independent from the WIPlevel within the examined range, only for a 4 day maximum throughput time a significant decrease is observed with a WIPlevel of 130.

The limits from which on selection at the repairmen needs to take place where set at 310, 247, 185 and 123 products for a maximum throughput time of 10, 8, 6 and 4 days respectively. This in line with formula 8.2

Returns per year:	15000		20000		30000	
Nr of days maximum	WIPlevel	Total value	WIPlevel	Total value	WIPlevel	Total value
normal value distribution, normal processing times						
4	60 - >130	1599115	40 - >130	1967969	40 - 100	2567426
6	60 - >130	1613057	40 - >130	1953200	40 - >130	2570547
8	60 - >130	1580871	40 - >130	1953679	40 - >130	2553406
high value distribution normal processing times						
4	30 - 100	2424829	40 - 100	2979627	30 - 100	3958820
6	30 - >130	2425793	40 - >130	2965295	30 - >130	3991449
8	30 - >130	2393510	40 - >130	2944296	30 - >130	3961041
10					30 - >130	3946488
low value distribution, normal processing times						
4	40 - 100	1032623	40 - 100	1238213	40 - 100	1600518
6	40 - >130	1022655	40 - >130	1224460	40 - >130	1592906
8	40 - >130	1019177	40 - >130	1220887	40 - >130	1591459
10					40 - >130	1592951
normal value distribution, low processing times						
4	60 - 100	1704114	40 - 100	2086327	40 - 100	2746918
6	60 - >130	1675311	40- >130	2069039	40- >130	2732208
8	60 - >130	1676316	40- >130	2063444	40- >130	2715536
10	60 - >130	1672346				

Table 13.10: Total value of repairs and WIPlevel intervals for Redesign 3, values in €

The attained values do not differ significantly from the second redesign, no significant maximum value differences are observed for different desired throughput times. Again the WIP is less important to achieve the results, as the intervals are wider. The aggregate intervals regardless of the value distribution or the number of returns are displayed in Table 13.11. For all maximum throughput times the intervals are positive.

Maximum throughput time	WIPlevel interval
4	60 - 100
6	60 - >130
8	60 - >130
10	60 - >130

Table 13.11.: Aggregate WIPlevel intervals for redesign 3

13.5. Redesign 1 to 3: A conclusion

Appendix 13.4 displays a table indicating the value of the repairs as percentage of the upper boundary for the situation. As can be seen all a high value is attainable in all considered scenarios. The values are all above 94% of the upper bound. The scenarios with low processing times even have percentages of 97% and higher. For the scenarios with normal processing times the performance slightly decreases with an increase in value distribution. This is probably caused by the seasonal effects and the resulting difference in value of the arrivals which is larger when more expensive products arrive. This seasonality is also the reason that the upper bound is never reached.

The first redesign leads to very good results if the maximum throughput time is 10, 8 and 6 days. The risk on useless repair can be controlled whilst the repairmen are not out of work regularly. However, at lower maximum throughput times this is not possible anymore. In these scenarios, where products are repaired late, the priority rule can slightly decrease the probability on this and thus increase the total value. However the effect of the priority rule is rather small. Besides, the increase in total value can be accompanied by a decrease in the service for non-priority products. With and without priority rule the first redesign there are scenarios in which good results cannot be guaranteed by the first redesign.

The second and third redesigns do perform well in all considered scenarios. On attained value we cannot state one is better then the other. The third redesign however is less sensitive to WIPlevels, as can be seen at the wider WIPlevel intervals for this redesign.

When we consider variations outside the scope of the simulation there are differences in the performance of the redesigns. The performance of the redesigns is now calculated for a given constant capacity and a given distribution of the arrivals. However in practice it can be that employees get sick causing less capacity for some days or weeks. On the other hand it can be that due to reasons outside the scope of the simulation, e.g. special events like the European Championship soccer, problems at the delivering logistic service providers, the arrival of products is temporarily very high or very low. These extreme cases are handled differently in the redesigns.

For the first two redesigns sickness leaves can cause late repairs since all products in the WIP need to be repaired and the temporary decrease in capacity makes sure this takes longer. In Redesign 3 when a sickness leave occurs the WIPlevel at the repairmen can be increased to cope with the decrease in capacity. This leads to more handling and thus slightly fewer repairs, however these repairs are done on time.

An unexpected temporary large decrease in the arrivals will leave the repairmen out of work. The speed at which they are out of work is dependent on the WIPlevel used for control. The higher this level is the longer the temporal decrease can be without affecting performance. The WIPcontrol level can be set highest in Redesign 3, this redesign is therefore more robust against unexpected temporal large decreases in arrivals.

A temporary large increase in the number of arrivals on the other hand will in Redesign 1 cause the WIP to rise and products to be repaired late. In Redesign 2 this is countered by the WIPcap leading to a better performance, however it is then not sure whether the right products are repaired. In Redesign 3 WIP would rise just as in Redesign 1, but then a raise of the level for repair at the repairmen would prevent products from being late. This would lead to an increase in handling, but the more lucrative products are repaired on time.

We can conclude that Redesign 3 is most robust against the large unexpected changes. This redesign also leads to good results in the simulation and therefore is the best of the first three redesigns.

14. Redesign 1 to 3: results for 1 day maximum throughput time

Although, according to RICOLEC, four days is, in practice, the minimal maximum throughput time for the repair of products, still it is interesting, from an academic point of view, to see how the different models perform under even shorter maximum processing times. Therefore we have shortly simulated all three designs for the situation in which the maximum throughput time is only 1 day. Thus products brought today need to be fixed tomorrow. Here we will first discuss the simulation settings used, after which the results for the models will be compared.

14.1. Simulation settings & performance evaluation

The WIP control levels were adjusted, compared to the simulation in chapter 13. This because the repairmen on average only repair 34 products a day, thus control levels higher then 34 can never lead to high results. The redesigns were therefore simulated with control levels of 10 and 20 products.

In this simulation only the normal situation, with normal processing times and a normal value distribution was simulated. The priority rule in redesign 1 was not varied, all products were repaired first come first served. The percentage of priority products was also kept constant.

For redesign 2 and 3 the WIPcap and the WIPlimit were set on 30 products by solving formulas 7.2 and 8.1 for 1 day capacity. The maximum attainable value for each of the redesigns is equal to the maximum value discussed in section 13.1. The performance of the redesigns will be evaluated based on the attained value of the repairs as a percentage of the maximum value.

14.2. Results for redesign 1 to 3

Table 14.1 displays the results for the simulation of the different situations. It also displays the percentage of the maximum attained by the different redesigns. As can be seen the third redesign performs best in all circumstances. The differences between the first and third redesign are significant in all circumstances except 15000 returns and a control level of 10 products. As can be seen significantly more products are repaired under redesign 2 and 3 than under redesign 1. Under the simulated circumstances the WIPcap is reached often causing, in contrast to in redesign 1 no late repairs and a higher total value of repairs, although only significant at a WIP control level of 20 with 15000 and 20000 returns.

Under the third redesign significantly more repairs are completed on time than under the first redesign and therefore this leads to significantly better results with respect to the total attained value in all simulated circumstances. This is due to the extra selection decision at the repairmen. The third redesigns also attains higher values than the second redesign in all simulated circumstances, however this is only significant at a WIP level of 10 products and for a WIP level of 20 products and 20000 returns. The differences in total value attained between 10 and 20 products within one redesign show that redesign three is less depended on the set WIP level then the other redesigns.

		15000 returns		20000 returns		30000 returns	
Redesign	WIPcontrol level	total value	Percentage	total value	Percentage	total value	Percentage
1	10	1342752	82.2%	1691534.1	84.5%	2137485.9	81.0%
2	10	1343004.9	82.2%	1706191.4	85.2%	2159200.5	84.5%
3	10	1394856	85.3%	1776198.3	88.7%	2277166.4	86.3%
1	20	1419677.7	86.9%	1755359.1	87.7%	2245174.5	85.1%
2	20	1476369.4	90.3%	1804946.6	90.2%	2268877	86.0%
3	20	1478530.4	90.5%	1819730	90.9%	2288635.7	86.8%
Maximum value:		1634430	100.0%	2001487	100.0%	2637870	100.0%

Table 14.1: Results under a maximum throughput time of 1 day

Redesign	WIPcontrol level	15000 returns	20000 returns	30000 returns
1	10	4613.7	5285	5462.7
2	10	4717.9	5264.8	5978
3	10	5575.2	6249.3	6417.1
1	20	6345.9	6535.2	6437.3
2	20	6727.8	6964.5	7251.9
3	20	7107.7	7373.5	7422.5

Table 14.2: products repaired on time under a maximum throughput time of 1 day

In conclusion we can state that under these extreme circumstances the third redesign functions best in terms of the attained value of the repairs.

15. Decreasing capacity: redesign 3, results

15.1. Capacity: the influence of a decrease in capacity

We have shortly examined the effect of decreasing the capacity available for repair. Only a decrease is examined since RICOLEC expects not to hire any new personnel when any of the present repairmen quits. This for the same reasons as it hires no new personnel on a temporary or fixed basis, being that the time needed to get acquainted with the repair work of the product assortment is very time consuming and, according to RICOLEC, the labor costs of new workers together with the possibility that new workers will leave the company quickly do not justify this learning period. We have examined three scenarios. All with a maximum throughput time of 4 days and normal processing times. This throughput time was chosen because the effect is expected to increase with a decrease in throughput time since then WIP needs to be controlled on a lower level and 4 days is the lowest practically possible, according to RICOLEC, throughput time. The effect of a capacity decrease was measured for Redesign 3, since this redesigns leads to the best performance in the simulation. The capacity levels considered are 2, 1,5 and 1 fulltime repairmen. The WIPlimits for the redesign were based on the considered capacity and calculated with formula 8.2. The upper bound on performance with these capacity levels for the considered scenarios can be found in table 15.1 and was calculated in the same manner as table 13.1.

	Capacity (persons):	1	1.5	2
Value distribution	Returns per year	Value (€)	Value (€)	Value (€)
normal value distribution	20000	1405006	1699670	1875280
high value distribution	30000	3200263	3560057	3859457
low value distribution	15000	701175	861600	975080

Table 15.1.: Upper bounds on the total value of repairs for different levels of capacity

Table 15.2 depicts the maximal attainable value and its percentage of the upper bound per capacity level and simulated circumstances. Graphs displaying the value of repairs per WIPcontrol level for the different scenarios can be found in Appendix 15. The graphs show that the total value is dependent upon the WIPlevel, a too high WIPlevel for control leads to a lower total value due to a lot of late repairs. A too low WIPlevel for control leads to a lower total value due to the repair of fewer products. This relation is most strongly shown in appendix figure 15.9.

	Capacity (persons):	1		1.5		2	
Value distribution	Returns per year	Value (€)	%	Value (€)	%	Value (€)	%
normal value distribution	20000	1254584	89.3%	1560478	91.8%	1774845	94.6%
high value distribution	30000	2974907	93.0%	3369213	94.6%	3681917	95.4%
low value distribution	15000	626446.4	89.3%	803492.8	93.3%	928129.8	95.2%

Table 15.2: Performance of Redesign 3 under different capacity for repair

The performance of Redesign 3 goes down with decreasing capacity. This is due to the lower WIPlevels for control that should be used to prevent excessive handling of repairs by the repairmen which carries the inherent risk that the repairmen are out of work as can be seen in the graphs in Appendix 15. However even if only one repairman is available and the maximum throughput time is only 4 days still at least 89% of the total value can be repaired. It is expected that the percentage will increase for longer maximum throughput times since then a higher WIPlevel for control can be used.

16. Design 4: results

16.1. Redesign 4: expected benefits

Due to the high performance attainable with the first three redesigns it is questionable whether redesign 4, with individual product access would lead to large further improvements.

In the fourth redesign no handling of the batches is needed anymore, but the individual handling times for the products are unknown. The maximum attainable value of the repairs when no handling is needed is depicted in table 16.1. In the table only the time needed for out of warranty repairs is subtracted from the total capacity.

Scenario/ returns per year	15000	20000	30000
normal value distribution, normal processing times	1647889	2009188	2664333
high value distribution, normal processing times	2531815	3135296	4174500
low value distribution, normal processing times	1047130	1276037	1635093
normal value distribution, low processing times	1712573	2130204	2794204

Table 16.1: Upper boundaries for the different scenarios without handling by repairmen, values in €

If we compare the values from table 16.1 with the values attainable by redesign 1 to 3 from chapter 13, we see it is in the ideal situation possible to increase the total value of repairs.

In practice, zero handling will be very difficult to realize. However even with zero handling the maximum will not be reached due to the fluctuations in arrivals in the year, which make it impossible to always repair the most lucrative products, as was also seen for redesigns 1 to 3. The need of handling decreases the attainable benefits of this redesign. We have examined the upper bound on performance for different handling times. These are displayed in Appendix 16. The upper bounds are obtained by calculating the maximum with increases of the total repair time per product. This increase then resembles the handling time per product needed to take the product from stock. Then the most profitable products are considered for repair until the capacity available for one year is filled. This does not take into account the maximum throughput times, making the calculations similar to the calculations underlying table 13.1.

Now to judge whether improvement can be made by Redesign 4, we subtracted the maximal attained values of Redesign 3, which are at least equally good than those of the other two redesigns. The potential improvement decreases with the handling time and for each scenario there is a handling time for which the upper bound on Redesign 4 is equal to the performance of redesign 3. Table 16.2 displays this handling time, being 1, 3, 5, 7 or 9 minutes for the different scenarios.

Returns per year:	15000	20000	30000
Nr of days maximum	minutes	minutes	minutes
normal value distribution, normal processing times			
4	5	3	5
6	5	3	5
8	7	3	7
10	5	5	7
high value distribution normal processing times			
4	7	7	5
6	7	7	5
8	9	9	5
10	9	7	5
low value distribution, normal processing times			
4	3	5	3
6	3	5	3
8	3	5	3
10	3	5	3
normal value distribution, low processing times			
4	1	3	3
6	3	3	3
8	3	3	3
10	3	3	3

Table 16.2: Break even handling times in minutes for Redesign 4

This analysis assumes no seasonal effects are apparent. Therefore in practice the handling times need to be smaller then suggested figures to obtain benefits from redesign 4. Overall an improvement, when the repairmen capacity is 2,5 men, is only likely when the handling time per product can be decreased compared to the batch scenario. The individual access therefore does not lead to significant higher performance, but a decrease in handling time can lead to an increase. However this decrease might also be attained while still handling the products in batches.

The redesign might become appealing when the repair capacity decreases to 1 or 1,5 repairman and the maximum throughput times decreases to 4 days, since then the third redesign performs less good. The functioning of redesign 4 does not depend on capacity if the products not repaired are taken out of the WIP and are handled by other employees than the repairmen. Then the repairmen can be kept working and no risk on late repairs is apparent. However this requires extra capacity of other employees.

17. Recommendations

This report focuses on answering two different research questions as stated in section 2.5. We will first discuss the recommendations for the first research question. After this the recommendations for the second research question will be discussed for each decision.

17.1. Insight in the failure of not repaired products

Currently RICOLEC does not know what causes the failure on not repaired products. However, as discussed in chapter 2 this information can be of use. Therefore the following research question was formulated:

How can RICOLEC obtain insight in the failure of its products in the field by testing products received in the warranty return flow?

Now for RICOLEC to attain insight in the failures of product type series a number of returned products need to be tested. In order to achieve considerable precision and confidence the number of tested products per series will be in the order of 20 to 30 products. The testing of the products with the current size and quality of the assortment will probably require less than 300 hours of a tester on a yearly basis. In order to facilitate the testing of the right amount of products the procedure developed in this report can be implemented to obtain fast and relatively detailed insight in the failure behavior of not repaired products based on IRIS codes. However, the testing procedure prescribes the testing of the first arriving returns. This to secure that the results of the tests are available rapidly. However this sample is not random and can therefore lead to biased results. This limits the statistical value of the procedure. The effect of sampling the first products compared to a random sample could be examined.

Also RICOLEC should look into the use of the results from the tests. In the near future procedures should be developed that assist in the timely and adequately use of the results, both with respect to communication to suppliers and improvements of product support. Also the test procedure results can be used in the purchase of new product types.

17.2 Processing of warranty returns

RICOLEC at the moment is unsure that it is processing its warranty returns in the right way and feels that this process can be improved upon, as stated in chapter 2. Therefore the following research question was formulated:

How should the submitted warranty claims and products flow be allocated to the different settlement/processing combinations in order to process the claims and products more cost-effectively?

This research question can be subdivided in partial research question each involving one decision in the process as it shown in figure 5.1. Therefore we will also address the recommendations for each decision separately

17.2.1. Repair or not? what and how much to repair

Four different redesigns were constructed. Of the first three redesigns the performance was determined by simulation. This showed that in the current situation with 10 days throughput time all three redesigns function equally well and with all redesigns close to optimal performance can be achieved. If the maximum throughput time is lowered to 4 days however, the second and third redesigns lead to better results than the first redesign. The performance of the first redesign in this situation can be improved by including a priority rule. However the improvement does not lead to the same high results as attained with redesign 2 and 3. Taking into account not simulated variations we have to conclude that redesign 3 is the most robust redesign and will lead to equal or better performance than the first and second redesign in all relevant situations. The performance of this redesign decreases slightly with a decrease in capacity; however it remains close to or above 90% of the upper boundary.

The fourth redesign will, with the current capacity, not lead to significant improvements unless the handling time of products can be reduced to very low levels. Therefore the implementation of this redesign is not recommended. The redesign might become interesting if both the maximum throughput time and capacity are severely lowered. However, the increase in performance will then be larger in percentage and smaller in value due to the lower maximum values.

We must note that the performance of the different redesigns was examined for a seasonal arrival pattern. However both the degree of seasonality and the variation in the arrivals were not varied since RICOLEC does not expect these variables to change. Still, variation in these variables might influence the result.

Concluding we recommend the implementation of the third redesign in view of expected future developments and robustness to unexpected variations. In the implementation the solution can be refined to better include two variables for which assumptions needed to be made in the simulation. Firstly, the probability of a failing repair was not taken into account in the simulation and in the formula to determine the profitability of repair. The probability that cannibalization was needed was not differentiated to product type in both the simulation and the measure of profitability. Both these variables can be measured in the newly made information system that also includes the redesign and can therefore be included in future refinements. Secondly, the repair times for the different products were not known precisely and had to be estimated based on interviews with the repairmen. The repairmen have demonstrated willingness to register their repair times and this can be included in the newly constructed system. The resulting repair times can be used to update and refine the redesign.

For the future RICOLEC can look into two other things that might lead to improvements in the processing of the returns. First, on a more conceptual basis, RICOLEC could look into the possibility of like-for-like repair in which it is not necessary to return the exact same (repaired) product, to a customer but just one of the same product type. This would alter the production control situation, production to stock could be partially applied possibly limiting the effect of seasonality, however it would probably not make its control easier. Besides this, it is far from guaranteed better results could be attained. Secondly RICOLEC can reduce the returns, especially returns with no technical failures, by better product support via e.g. brand websites and user-manuals.

17.2.2. Cannibalize or not?

We conclude that it is not economically attractive for RICOLEC to invest in the optimization of its stock keeping system to decide upon cannibalization. This due to the diversity in the used parts, the low quantities per part and the relatively low value of the parts together with the large requirements with respect to needed information to construct an optimal policy to determine which products to cannibalize. A simple policy was developed and to facilitate the decision making this policy can be implemented. However, this policy is limited with respect to the control of the stocking for cannibalization of products and the stock keeping of the products to be cannibalized. In the future RICOLEC could look into the incorporation of demand for cannibalized parts into the procedure to improve upon the selection of products, at the moment this was not possible due to a lack of data with respect to the use of cannibalized parts.

17.3.3. Replace or reimburse?

The decision whether to replace a product for a new one or reimburse a submitter needs to take into account various other considerations than purely financial ones. Besides this the physical possibility to replace a product is variable and unknown. Therefore we cannot conclude when which option should be chosen. If financial considerations are the sole concern then the proposed decision structure can be implemented. However, since non-financial motives are leading in this decision the proposed decision structure is only of little practical use. RICOLEC wishes to fulfill the wishes of the claim submitter with respect to replacement or reimbursement from the viewpoint of customer service. However these wishes are not known for all the customers. Therefore it might be interesting to see what the wishes of the submitters are with respect to this decision. Then RICOLEC can base its decisions better upon these wishes.

18. Conclusion on the contribution to academic literature

18.1. Contribution to the academic literature

When the maximum throughput times are large all redesigns can lead to high performance. The different order acceptance policies do not lead to different results. However when throughput times or Due Dates become more stringent the more elaborated order acceptance policies of Redesign 2 and Redesign 3 perform better than the simple order acceptance policy of Redesign 1. Translating this to Kingsman's (2000) model the control over both input and queue only adds to the performance of a production system compared to only input control in case of stringent maximum throughput times, as is evident from the better performance of redesign 3 under short practical maximum throughput times and maximum throughput times of 1 day. Stringent maximum throughput times are defined as throughput times where no WIP level can be chosen that both controls the risk on late delivery as well as a high occupancy rate.

These findings need to be placed into perspective. In this report the different order acceptance policies have been tested under numerous scenarios, however all with seasonality and a fixed variation. Also the cost function was not varied. The order acceptance policies should be examined for different arrival scenarios and cost functions (e.g. a cost function based on the tardiness of products) in order to generalize the insights.

Still, the conclusion is similar to the conclusions drawn by ten Kate (1994) and Wester *et al* (1992) that conclude the integration of scheduling and order acceptance only yields better results for stringent Due Dates. Although we do not consider scheduling we do extend the order acceptance function to account for the status of the system in more detail.

With respect to the performance of production control mechanisms with a WIPcap in situations with variable rewards it can be concluded that when the WIPcap is close to the WIP level used for control the average value of repairs decreases because of the refusal to repair lucrative products as was expected by Van Ooijen and Bertrand (2003). This effect decreases with the difference between the WIPcontrol level and the WIPcap.

Lastly it was shown that under large maximum throughput times close to optimal performance can be achieved with batch stock keeping of products. Also when throughput times become more stringent the results attainable with batch stock keeping are high, although only for more complex order acceptance policies. However with stringent throughput times and a small capacity it might be that individual product stock keeping and the larger opportunities with respect to scheduling lead to better performance than batch stock keeping. Simulation of the situation in which products are individually accessible is needed to draw definite conclusion in this respect.

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Presentations:

How IRIS Works, presentation of the EICTA

IRIS_course, presentation of the EICTA

Appendix

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Appendix 3

Appendix 3.1: Search method & terms

Table 3.1 displays the terms used in searches for relevant literature with respect to production control, order acceptance and scheduling. The searches were conducted using the Abi-Inform and Science Direct databases as indicated in the table. The terms were searched for in the citation, abstract and keywords. The reliance of an article was firstly judged on article title and secondly on abstract. Besides this potentially relevant articles cited in the found articles were explicitly searched for using Abi-Inform, Science Direct, Jstor, Springerlink and Taylor and Francis databases.

Abi-Inform:	**Science direct:**
Repair, Refund	Repair, Refund
Repair, throughput time	Repair, reimbursement
Repair, planning, replacement	Repair, throughput time
Repair, reverse logistics	Repair, planning, replacement
Repair, value-of-time	Repair, scheduling
Remanufacturing, value-of-time	Repair, reverse logistics
Remanufacturing, value-of-information	Repair, value-of-time
Repair, value-of-time	One machine scheduling, linear programming
Repair, value-of-information, ''	Order acceptance, scheduling
Remanufacture, value-of-information	Order acceptance, 2-stage
Remanufacture, value-of-time	Preliminary, order acceptance
Repair-planning	Selection, order-acceptance
Reverse logistics, replace	Make-to-order, order-acceptance
Reverse logistics, replacement	Order acceptance, throughput time
Repair, warranty	Job selection, throughput time
One machine scheduling, linear programming	Job selection, sequencing
Reverse logistics, conwip	Arrival rate control
Supply uncertainty, conwip	Conwip
Make-to-order, conwip	Workload regulation
Supply, conwip	Order acceptance, Due date
Over supply, conwip	WIP, tardiness
Single machine, conwip	Late jobs, one machine
Work in process AND Production planning	Order acceptance, late products
Batch, sequencing	Order acceptance, outsourcing
Workload regulation	Scheduling, outsourcing
Order selection	Production planning, order acceptance
Scheduling, outsourcing	Queue, termination control
Production planning, outsourcing	
Production planning, order acceptance	

Table 3.1: Search terms per Database

Appendix 3.2: Example part of IRIS-code table as used by RICOLEC

1	CONSTANT
2	MET TUSSENPOZEN
3	NA ENIGE TIJD
4	BIJ HOGE TEMPERATUUR
5	BIJ LAGE TEMPERATUUR
6	BIJ HET SCHAKELEN
7	BIJ TRILLING / SCHOKKEN / BEWEGING
8	IN EEN VOCHTIGE / NATTE / REGENACHTIGE / SNEEUWRIJKE OMGEVING
9	IN DROGE OMGEVING
A	VEROORZAAKT DOOR SCHADE VAN BUITENAF
B	NA BLIKSEMINSLAG
C	OP BEPAALDE STATIONS / KANALEN / SOFTWARE / FREQUENTIEBAND / FUNCTIE / NETWERK
D	BIJ BEPAALDE STANDAARD OF SYSTEEM
E	OP EEN KANAAL
F	OP BEPAALDE INGANGEN
G	BIJ BEPAALDE UITGANGEN
H	IN DE STANDBY (WACHT) / OFF STAND
J	OP HET EDIT-PUNT
K	WANNEER AANGESLOTEN OP SPECIFIEKE EXTERNE APPARATUUR OF ADAPTER
L	VOCHTSCHADE
M	GEDURENDE KORTE TIJD NA INSCHAKELEN
N	NA HET MAKEN VAN EEN KOPIE
O	ONDER ZWARE CONDITIES / HOGE BELASTING
P	BIJ HET UITSCHAKELEN
Q	ALLEEN TIJDENS ZENDEN / SCHRIJVEN
R	ALLEEN TIJDENS ONTVANGST / LEZEN
S	ALLEEN MET BEPAALDE MEDIA
T	ALLEEN BIJ HET BEHANDELEN VAN EEN SPECIFIEK GEDEELTE OP HET MEDIUM
U	ALLEEN OP BEPAALDE GEOGRAFISCHE LOCATIES

		1	GEEN WERKING	2	NIVEAU
1	ALGEMEEN	110	VOEDING OF WERKING	120	OPLADEN
		111	DOET NIETS	121	LAADT NIET OP
		112	DOET NIETS OP LICHTNET ADAPTOR	122	LAADT NIET VOLLEDIG OP
		113	DOET NIETS OP BATTERIJ(EN)	123	OPLAADTIJD TE LANG
		114	DOET NIETS MET OPLAADBARE BATTERIJ(EN)	12X	ANDER OPLAADPROBLEEM
		115	DOET NIETS OP ZONNECELLEN		
		116	DOET NIETS OP AUTO ACCU		
		117	WERKT KORTSTONDIG		
		118	SCHAKELT NIET UIT		
		119	SCHAKELT NIET IN VAN/UIT STANDBY		
		11A	ALLEEN VOEDING WERKT		
		11B	HERHAALDELIJK POWER ON / OFF		
		11C	EXTERNE (NET) ZEKERINGEN SLAAN DOOR		
		11D	SET SCHAKELT VANZELF UIT		
		11E	BACKUP-BATTERIJ		
		11F	GEEN WERKING		
		11G	GEEN AUTOMATISCHE AAN- / UITSCHAKELING		
		11H	INTERNE BEVEILIGINGSZEKERING / -SCHAKELAAR SPREEKT AAN		
		11J	OPLAADBARE BATTERIJ NIET HERKEND		
		11K	APPARAAT START MET VERTRAGING		
		11X	ANDER PROBLEEM MET VOEDING		
2	ONTVANGEN / ZENDEN	210	ONTVANGST OF VERBINDING	220	ONTVANGSTNIVEAU OF VERBINDING
		211	GEEN AM ONTVANGST	221	ZWAKKE AM ONTVANGST
		212	GEEN FM ONTVANGST	222	ZWAKKE FM ONTVANGST
		213	GEEN KORTE GOLF ONTVANGST	223	ZWAKKE KORTE GOLF ONTVANGST
		214	GEEN VHF ONTVANGST	224	ZWAKKE VHF ONTVANGST
		215	GEEN UHF ONTVANGST	225	ZWAKKE UHF ONTVANGST
		216	GEEN BS ONTVANGST	226	ZWAKKE BS ONTVANGST
		217	GEEN CS ONTVANGST	227	ZWAKKE CS ONTVANGST
		218	GEEN HDTV ONTVANGST	228	ZWAKKE HDTV ONTVANGST
		219	GEEN GPS / DGPS ONTVANGST	229	ZWAKKE GPS / DGPS ONTVANGST
		21A	GEEN ONTVANGST VAN DIGITALE UITZENDING	22A	SLECHTE ONTVANGST VAN DIGITALE UITZENDING
		21B	GEEN INFRAROOD ONTVANGST	22B	SLECHTE INFRAROOD ONTVANGST
		21C	GEEN KIESTOON	22X	ANDER ONTVANGSTNIVEAU- / VERBINDINGSNIVEAUPROBLEEM
		21D	GEEN MODEM / TELEFOON / FAX VERBINDING		
		21E	MODEM / TELEFOON ANTWOORDT NIET / GEEN CARRIER		
		21F	GEEN NETWERKVERBINDING / NETWERKINITIALISATIE FAALT		
		21X	ANDER PROBLEEM MET ONTVANGST OF VERBINDING		

Figure 3.1: part of IRIScode table as used by RICOLEC (in Dutch)

Distribution characteristics & fit	2006
mean	77.0531
standard deviation	29.0488
P-Value	0.112187

Table 4.2 Distribution parameters arrival in 2006

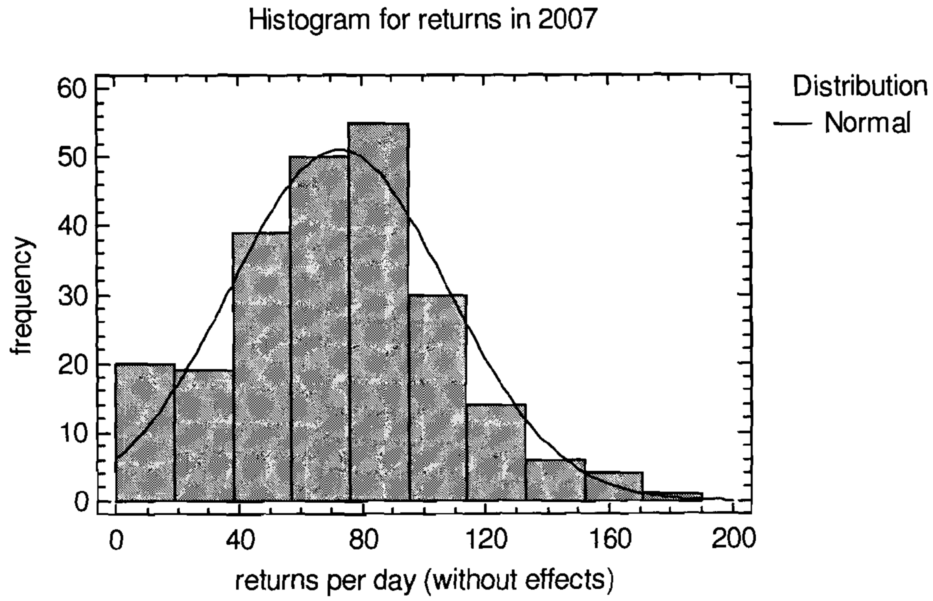


Fig 4.5 Normal distribution histogram for 2007

Distribution characteristics & fit	2007
mean	72.5991
standard deviation	35.3225
P-Value	0.723948

Table 4.3 Distribution parameters arrival in 2007

4.1.3 Warranty return rates per product group in 2006

Product group	total sales untill 2006	total repairs untill 2006	total WRR %
KTV	54049	2107	3.90%
LCD-TV	6182	264	4.27%
COMBI LCD-TV/DVD	2317	27	1.17%
COMBI/TV/DVD/VIDEO	40900	2618	6.40%
PORT.LCD/COMBI	74664	2842	3.81%
dvd-speler	102064	4301	4.21%
video	38007	990	2.60%
audio-set	146368	6928	4.83%
port.radio/cd	295979	9239	3.12%
discman	94415	4102	4.34%
klokradio	50881	406	1.06%
mp3-speler	180662	18249	10.10%
autoradio	1411	257	18.21%
radio	3754	44	1.17%
dect telefoon	118436	5232	0.044175757
PMR	2711	7	0.002582073

Table 4.4. Warranty return rates per product group

4.1.4. Division of the returns over the product groups in 2006

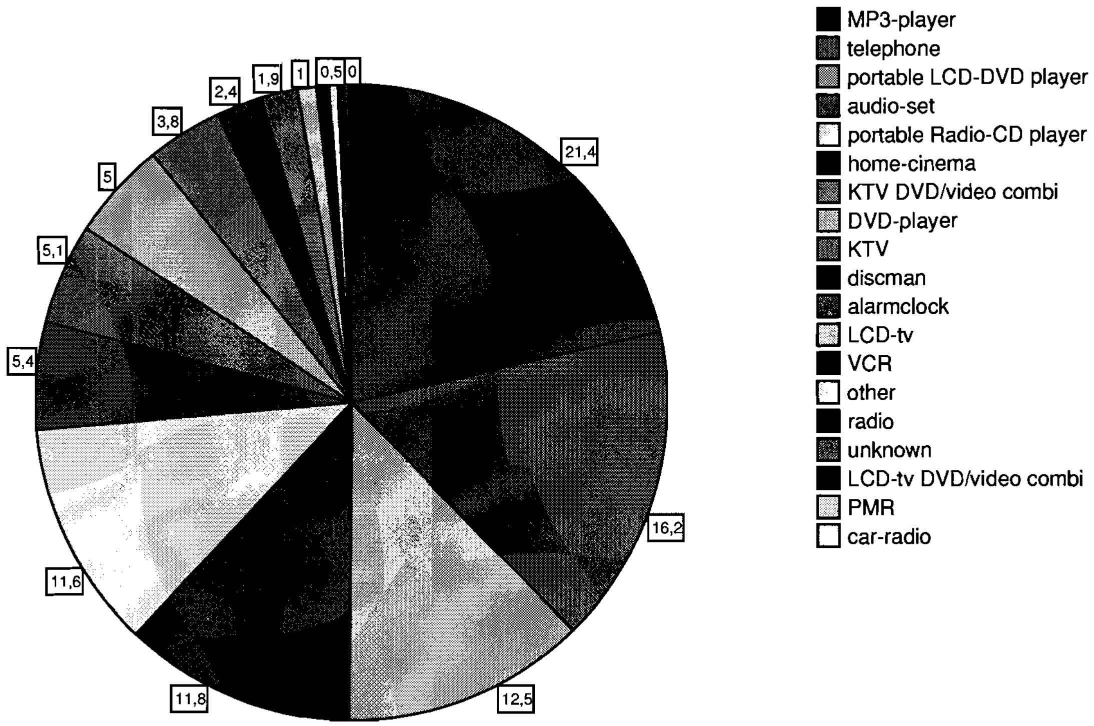


Fig. 4.6.: total returns division in product groups

4.1.5. Time between purchase and failure

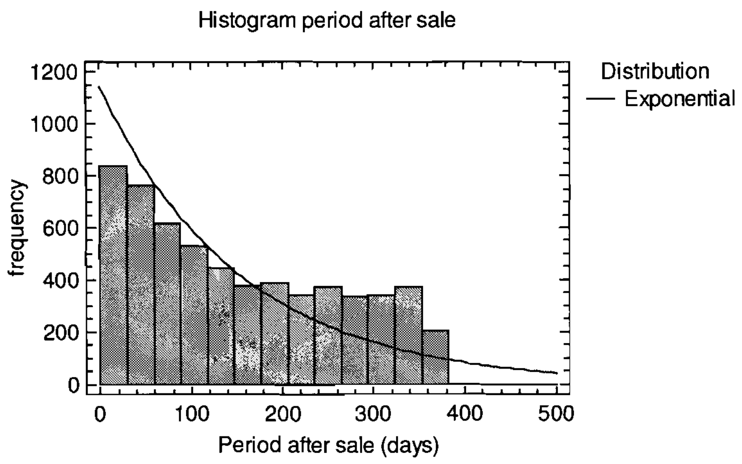


Fig. 4.7. Period between purchase and warranty claim for 1 year warranty products

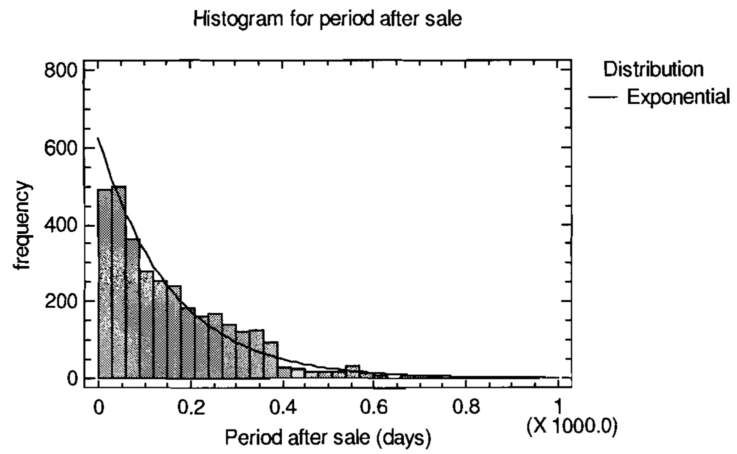


Fig. 4.8 a histogram for the period between purchase and claim filing for 2 year warranty products

Appendix 4.2: Returns division returns in product groups in 2006

4.2.1. Returns not related to warranty claims in 2006

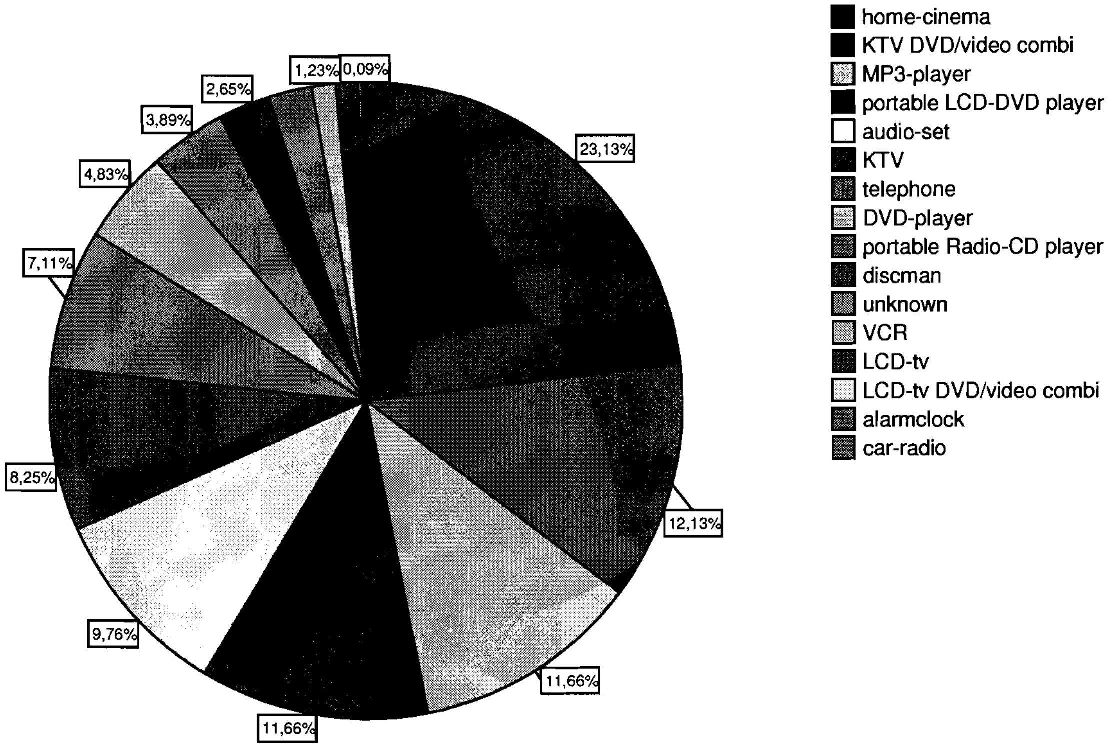


Figure 4.9: division in product groups of returns out of warranty

4.2.2. Warranty returns per productgroup in 2006

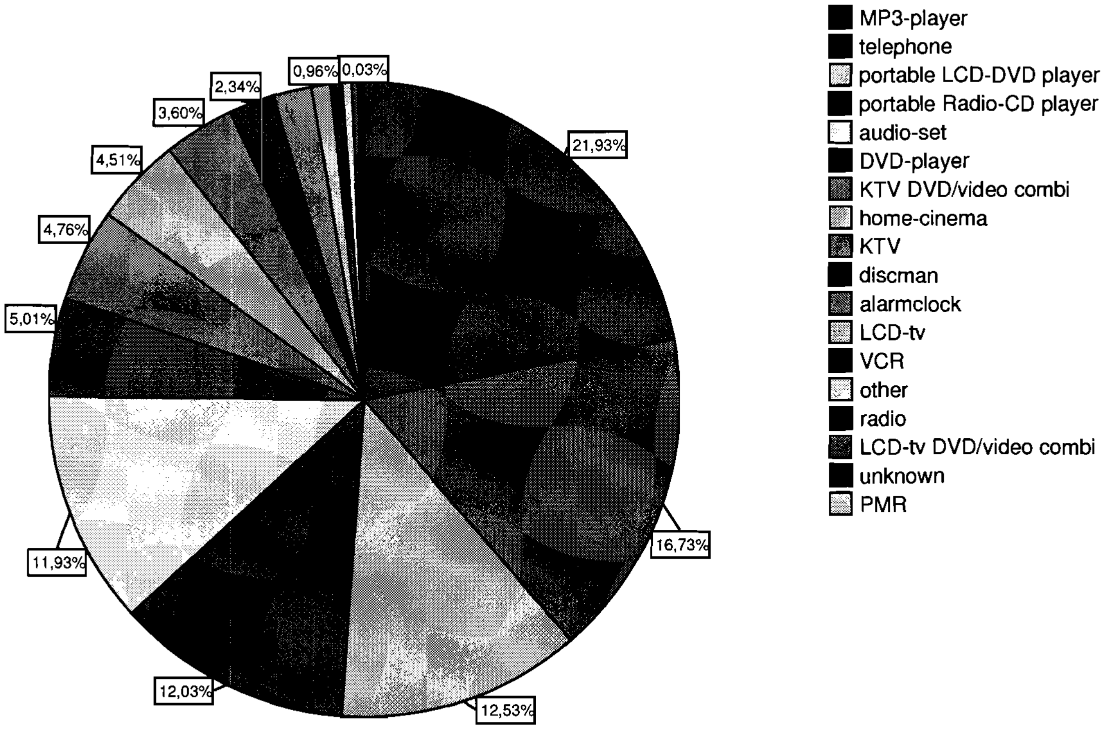


Fig. 4.10. Division of the warranty returns in product groups

4.2.3. Division in product groups of not repaired warranty returns in 2006

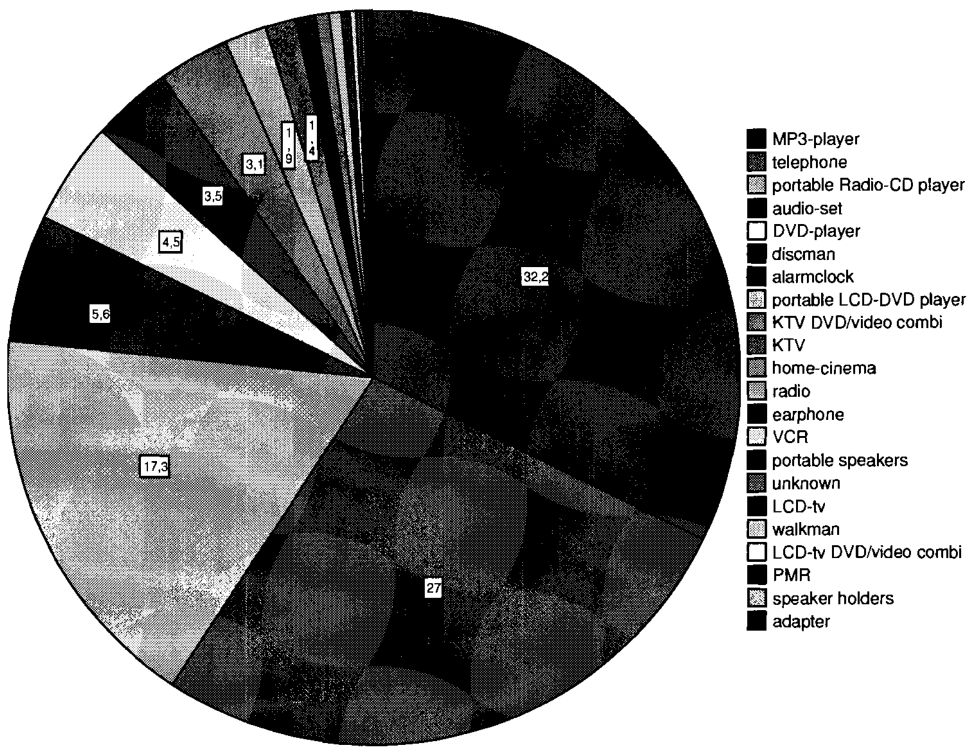


Figure 4.11: division of not-repaired warranty products

4.2.4. Percentage of products covered under warranty repaired per product group & product type in 2006

The tables show the number and percentage of product groups/types processed by the repair department and not processed by the repair department thus solely by the collection department.

These tables relate to the tables in Appendix 4.4. in that here the percentage of repaired products is shown. Appendix 4.4. then shows the failures, by means of IRIScode classification, of the products that were processed by the repair department.

Productgroup			Repair department		Total
			Yes	No	
Productgroup	Alarmclock	Count	1	389	390
		% within productgroup	,3%	99,7%	100,0%
	audio-set	Count	1685	681	2366
		% within productgroup	71,2%	28,8%	100,0%
	Discman	Count	34	430	464
		% within productgroup	7,3%	92,7%	100,0%
	DVD-player	Count	445	548	993
		% within productgroup	44,8%	55,2%	100,0%
	home-cinema	Count	827	67	894
		% within productgroup	92,5%	7,5%	100,0%
	KTV	Count	615	99	714
		% within productgroup	86,1%	13,9%	100,0%
	KTV DVD/video combi	Count	777	166	943
		% within productgroup	82,4%	17,6%	100,0%
	LCD-tv	Count	176	15	191
		% within productgroup	92,1%	7,9%	100,0%
	LCD-tv DVD/video combi	Count	16	11	27
		% within productgroup	59,3%	40,7%	100,0%
	MP3-player	Count	379	3970	4349
		% within productgroup	8,7%	91,3%	100,0%
	Other	Count	1	93	94
		% within productgroup	1,1%	98,9%	100,0%
	PMR	Count	0	5	5
		% within productgroup	,0%	100,0%	100,0%
	portable LCD-DVD player	Count	2262	222	2484
		% within productgroup	91,1%	8,9%	100,0%
	portable Radio-CD player	Count	252	2134	2386
		% within productgroup	10,6%	89,4%	100,0%
	Radio	Count	4	65	69

		% within productgroup	5,8%	94,2%	100,0%
	Telephone	Count	6	3312	3318
		% within productgroup	,2%	99,8%	100,0%
	Unknown	Count	3	17	20
		% within productgroup	15,0%	85,0%	100,0%
	VCR	Count	88	33	121
		% within productgroup	72,7%	27,3%	100,0%
Total		Count	7571	12257	19828
		% within productgroup	38,2%	61,8%	100,0%

Table 4.5. Repair percentages aggregated per product group

MP3-player			Repair department		Total
			Yes	No	
Type	DA1128	Count	2	0	2
		% within Type	100,0%	,0%	100,0%
	DA1256	Count	12	2	14
		% within Type	85,7%	14,3%	100,0%
	IDOLSBW	Count	0	7	7
		% within Type	,0%	100,0%	100,0%
	IDOLSGN	Count	2	2	4
		% within Type	50,0%	50,0%	100,0%
	IDOLSMA	Count	0	5	5
		% within Type	,0%	100,0%	100,0%
	IDOLSOR	Count	0	4	4
		% within Type	,0%	100,0%	100,0%
	IMP4128	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
	IMP7256	Count	2	0	2
		% within Type	100,0%	,0%	100,0%
	IMP8512	Count	5	1	6
		% within Type	83,3%	16,7%	100,0%
	MP5712	Count	0	9	9
		% within Type	,0%	100,0%	100,0%
	MP5756	Count	6	42	48
		% within Type	12,5%	87,5%	100,0%
	MP5856ED	Count	0	18	18
		% within Type	,0%	100,0%	100,0%
	PMP2020	Count	10	0	10
		% within Type	100,0%	,0%	100,0%
	STYXX10128WT	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	STYXX10128ZR	Count	0	4	4
		% within Type	,0%	100,0%	100,0%
	STYXX101GZR	Count	0	2	2
		% within Type	,0%	100,0%	100,0%
	STYXX10256WT	Count	0	3	3

		% within Type	,0%	100,0%	100,0%
	STYXX10256ZR	Count	2	15	17
		% within Type	11,8%	88,2%	100,0%
	STYXX10512	Count	3	7	10
		% within Type	30,0%	70,0%	100,0%
	STYXX111GR	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	STYXX11256RWT	Count	0	8	8
		% within Type	,0%	100,0%	100,0%
	STYXX11512R	Count	3	7	10
		% within Type	30,0%	70,0%	100,0%
	STYXX12256ZT	Count	0	2	2
		% within Type	,0%	100,0%	100,0%
	STYXX12512ZT	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	STYXX15128ZW	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	STYXX16256WT	Count	0	2	2
		% within Type	,0%	100,0%	100,0%
	STYXX16512WT	Count	1	9	10
		% within Type	10,0%	90,0%	100,0%
	STYXX25512GN	Count	0	3	3
		% within Type	,0%	100,0%	100,0%
	STYXX25512RGN	Count	0	3	3
		% within Type	,0%	100,0%	100,0%
	STYXX25512RZT	Count	0	3	3
		% within Type	,0%	100,0%	100,0%
	STYXX30128ZR	Count	10	1	11
		% within Type	90,9%	9,1%	100,0%
Total		Count	59	163	222
		% within Type	26,6%	73,4%	100,0%

Table 4.6.: repair percentage for MP3-players.

Telephone			Repair department		Total
			Yes	No	
Type	6131	Count	0	64	64
		% within Type	,0%	100,0%	100,0%
	6132	Count	0	2	2
		% within Type	,0%	100,0%	100,0%
	6141	Count	0	59	59
		% within Type	,0%	100,0%	100,0%
	6142	Count	0	37	37
		% within Type	,0%	100,0%	100,0%
	ME40501	Count	2	77	79
		% within Type	2,5%	97,5%	100,0%
	ME40504	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	ME40511	Count	0	37	37
		% within Type	,0%	100,0%	100,0%
	ME40512	Count	1	70	71
		% within Type	1,4%	98,6%	100,0%

ME40513	Count	0	37	37
	% within Type	,0%	100,0%	100,0%
ME40514	Count	0	6	6
	% within Type	,0%	100,0%	100,0%
ME40521	Count	1	727	728
	% within Type	,1%	99,9%	100,0%
ME40522	Count	2	666	668
	% within Type	,3%	99,7%	100,0%
ME40523	Count	0	285	285
	% within Type	,0%	100,0%	100,0%
ME40524	Count	0	262	262
	% within Type	,0%	100,0%	100,0%
ME40561	Count	0	100	100
	% within Type	,0%	100,0%	100,0%
ME40562	Count	0	300	300
	% within Type	,0%	100,0%	100,0%
ME40563	Count	0	57	57
	% within Type	,0%	100,0%	100,0%
ME40564	Count	0	34	34
	% within Type	,0%	100,0%	100,0%
ME40661	Count	0	23	23
	% within Type	,0%	100,0%	100,0%
ME40662	Count	0	45	45
	% within Type	,0%	100,0%	100,0%
ME40662B	Count	0	4	4
	% within Type	,0%	100,0%	100,0%
ME42511BW	Count	0	3	3
	% within Type	,0%	100,0%	100,0%
ME42511BX	Count	0	1	1
	% within Type	,0%	100,0%	100,0%
ME42511MA	Count	0	4	4
	% within Type	,0%	100,0%	100,0%
ME42511PK	Count	0	8	8
	% within Type	,0%	100,0%	100,0%
ME42511TI	Count	0	9	9
	% within Type	,0%	100,0%	100,0%
ME42511TN	Count	0	58	58
	% within Type	,0%	100,0%	100,0%
ME42511WT	Count	0	128	128
	% within Type	,0%	100,0%	100,0%
ME42511ZT	Count	0	11	11
	% within Type	,0%	100,0%	100,0%
ME42512	Count	0	4	4
	% within Type	,0%	100,0%	100,0%
ME42512TN	Count	0	104	104
	% within Type	,0%	100,0%	100,0%
ME42512WT	Count	0	52	52
	% within Type	,0%	100,0%	100,0%
ME42512ZT	Count	0	9	9
	% within Type	,0%	100,0%	100,0%
ME42513WT	Count	0	7	7

		% within Type	,0%	100,0%	100,0%
	ME50511ZT	Count	0	5	5
		% within Type	,0%	100,0%	100,0%
	ME50512ZT	Count	0	4	4
		% within Type	,0%	100,0%	100,0%
	ME50513ZT	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	ME60511RZR	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	ME60512RZR	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	ME60513RZR	Count	0	6	6
		% within Type	,0%	100,0%	100,0%
	ME6051R1	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	ME71581	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	NCR35CD	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
Total		Count	6	3312	3318
		% within Type	,2%	99,8%	100,0%

Table 4.7.: Repair percentage for telephones

Portable LCD/DVD player			Repair department		Total
			Yes	No	
Type	ACV6507D	Count	27	3	30
		% within Type	90,0%	10,0%	100,0%
	APV4300MB	Count	16	0	16
		% within Type	100,0%	,0%	100,0%
	APV5607B	Count	72	7	79
		% within Type	91,1%	8,9%	100,0%
	APV5608B	Count	19	11	30
		% within Type	63,3%	36,7%	100,0%
	APV6107SL	Count	50	7	57
		% within Type	87,7%	12,3%	100,0%
	ECV6605	Count	29	1	30
		% within Type	96,7%	3,3%	100,0%
	ECV6607	Count	183	12	195
		% within Type	93,8%	6,2%	100,0%
	ECV6707X	Count	148	6	154
		% within Type	96,1%	3,9%	100,0%
	EPV6007	Count	5	0	5
		% within Type	100,0%	,0%	100,0%
	EPV6210X	Count	18	2	20
		% within Type	90,0%	10,0%	100,0%
	NPD2100X	Count	161	37	198
		% within Type	81,3%	18,7%	100,0%
	NPD3070	Count	7	4	11
		% within Type	63,6%	36,4%	100,0%
	NPD3070TWINX	Count	104	21	125
		% within Type	83,2%	16,8%	100,0%

	NPD4070X	Count	155	27	182
		% within Type	85,2%	14,8%	100,0%
	PVS1080	Count	17	6	23
		% within Type	73,9%	26,1%	100,0%
	PVS123	Count	48	2	50
		% within Type	96,0%	4,0%	100,0%
	PVS12621	Count	42	7	49
		% within Type	85,7%	14,3%	100,0%
	PVS1370	Count	166	13	179
		% within Type	92,7%	7,3%	100,0%
	PVS162W	Count	25	0	25
		% within Type	100,0%	,0%	100,0%
	PVS1950	Count	210	17	227
		% within Type	92,5%	7,5%	100,0%
	PVS1950NA	Count	139	7	146
		% within Type	95,2%	4,8%	100,0%
	PVS1960	Count	11	0	11
		% within Type	100,0%	,0%	100,0%
	PVS1970	Count	83	4	87
		% within Type	95,4%	4,6%	100,0%
	PVS1971	Count	368	13	381
		% within Type	96,6%	3,4%	100,0%
	PVS6970	Count	159	15	174
		% within Type	91,4%	8,6%	100,0%
Total		Count	2262	222	2484
		% within Type	91,1%	8,9%	100,0%

Table 4.8.: Repair percentage for portable LCD players

Portable Radio-CD player			Repair department		Total
			Yes	No	
Type	AJ4140	Count	0	281	281
		% within Type	,0%	100,0%	100,0%
	AJC2500	Count	15	14	29
		% within Type	51,7%	48,3%	100,0%
	AJC3200	Count	1	3	4
		% within Type	25,0%	75,0%	100,0%
	AJC3200ZT	Count	2	0	2
		% within Type	100,0%	,0%	100,0%
	AJC3250	Count	5	63	68
		% within Type	7,4%	92,6%	100,0%
	AJC3300	Count	7	21	28
		% within Type	25,0%	75,0%	100,0%
	AJC3505	Count	89	103	192
		% within Type	46,4%	53,6%	100,0%
	AJC6041W	Count	55	63	118
		% within Type	46,6%	53,4%	100,0%
	AJC6041WWMA	Count	5	19	24
		% within Type	20,8%	79,2%	100,0%

	AJP4270R	Count	1	13	14
		% within Type	7,1%	92,9%	100,0%
	AJP4470R	Count	4	12	16
		% within Type	25,0%	75,0%	100,0%
	AJP4670R	Count	41	73	114
		% within Type	36,0%	64,0%	100,0%
	AJP5375UFC	Count	8	466	474
		% within Type	1,7%	98,3%	100,0%
	APRC10M	Count	0	14	14
		% within Type	,0%	100,0%	100,0%
	APRC50UC	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
	APRTC30M	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	CCD450	Count	0	4	4
		% within Type	,0%	100,0%	100,0%
	CCD450WT	Count	0	2	2
		% within Type	,0%	100,0%	100,0%
	CCD500ZR	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	CCD665ZR	Count	0	3	3
		% within Type	,0%	100,0%	100,0%
	CCD680BW	Count	0	26	26
		% within Type	,0%	100,0%	100,0%
	NCD400BW	Count	2	89	91
		% within Type	2,2%	97,8%	100,0%
	NCD400GN	Count	2	77	79
		% within Type	2,5%	97,5%	100,0%
	NCD400WT	Count	1	213	214
		% within Type	,5%	99,5%	100,0%
	NCD460BW	Count	0	19	19
		% within Type	,0%	100,0%	100,0%
	NCD460GN	Count	0	20	20
		% within Type	,0%	100,0%	100,0%
	NCD460WT	Count	1	13	14
		% within Type	7,1%	92,9%	100,0%
	NCD750	Count	0	20	20
		% within Type	,0%	100,0%	100,0%
	NCD760	Count	0	9	9
		% within Type	,0%	100,0%	100,0%
	NCD765	Count	0	3	3
		% within Type	,0%	100,0%	100,0%
	NCD910PS	Count	0	52	52
		% within Type	,0%	100,0%	100,0%
	NCD910RD	Count	2	71	73
		% within Type	2,7%	97,3%	100,0%
	NCD950UFC	Count	1	354	355
		% within Type	,3%	99,7%	100,0%
	PRCD610MP3	Count	8	12	20
		% within Type	40,0%	60,0%	100,0%
Total		Count	251	2134	2385

	% within Type	10,5%	89,5%	100,0%

Table 4.9.: Repair percentage for portable radio-CD players

Audio set			Repair department		Total
			Yes	No	
Type	AAV2080	Count	2	0	2
		% within Type	100,0%	,0%	100,0%
	AAV4720	Count	6	0	6
		% within Type	100,0%	,0%	100,0%
	AMP100	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
	CDP280	Count	4	2	6
		% within Type	66,7%	33,3%	100,0%
	CMA101	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	CMA105	Count	2	4	6
		% within Type	33,3%	66,7%	100,0%
	CMA110	Count	1	1	2
		% within Type	50,0%	50,0%	100,0%
	EMRM003	Count	4	12	16
		% within Type	25,0%	75,0%	100,0%
	EMRM015	Count	10	31	41
		% within Type	24,4%	75,6%	100,0%
	ES2	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	ES3	Count	0	44	44
		% within Type	,0%	100,0%	100,0%
	MICRO1500DSSW	Count	16	5	21
		% within Type	76,2%	23,8%	100,0%
	MICRO820CD	Count	20	1	21
		% within Type	95,2%	4,8%	100,0%
	MICRO820V	Count	136	11	147
		% within Type	92,5%	7,5%	100,0%
	MICRO830MP3	Count	83	12	95
		% within Type	87,4%	12,6%	100,0%
	MICRO850D	Count	14	1	15
		% within Type	93,3%	6,7%	100,0%
	NASS130	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	NMA150	Count	1	1	2
		% within Type	50,0%	50,0%	100,0%
	NMA200	Count	0	21	21
		% within Type	,0%	100,0%	100,0%
	NMA250	Count	1	18	19
		% within Type	5,3%	94,7%	100,0%
	NMA301	Count	37	65	102
		% within Type	36,3%	63,7%	100,0%
	NMA321	Count	3	4	7
		% within Type	42,9%	57,1%	100,0%
	NMA350UFC	Count	10	18	28
		% within Type	35,7%	64,3%	100,0%

NMA400P	Count	1	1	2
	% within Type	50,0%	50,0%	100,0%
NRB10HT	Count	0	4	4
	% within Type	,0%	100,0%	100,0%
NRB10ZT	Count	0	1	1
	% within Type	,0%	100,0%	100,0%
QX2100	Count	1	2	3
	% within Type	33,3%	66,7%	100,0%
QX2200	Count	3	1	4
	% within Type	75,0%	25,0%	100,0%
QX3700	Count	0	2	2
	% within Type	,0%	100,0%	100,0%
QX3700DV	Count	9	3	12
	% within Type	75,0%	25,0%	100,0%
QX4100	Count	19	4	23
	% within Type	82,6%	17,4%	100,0%
QX4100HT	Count	4	1	5
	% within Type	80,0%	20,0%	100,0%
QX4200	Count	36	8	44
	% within Type	81,8%	18,2%	100,0%
QX4200HT	Count	20	17	37
	% within Type	54,1%	45,9%	100,0%
QX5570UF	Count	24	5	29
	% within Type	82,8%	17,2%	100,0%
QX5690	Count	1	0	1
	% within Type	100,0%	,0%	100,0%
QX5690UFX	Count	276	208	484
	% within Type	57,0%	43,0%	100,0%
QXA6600R	Count	18	8	26
	% within Type	69,2%	30,8%	100,0%
QXA6600RMP3	Count	2	13	15
	% within Type	13,3%	86,7%	100,0%
QXA6600RX	Count	3	0	3
	% within Type	100,0%	,0%	100,0%
QXD2400	Count	3	0	3
	% within Type	100,0%	,0%	100,0%
QXD3305	Count	0	2	2
	% within Type	,0%	100,0%	100,0%
QXD3500	Count	16	2	18
	% within Type	88,9%	11,1%	100,0%
QXD3500ZR	Count	20	8	28
	% within Type	71,4%	28,6%	100,0%
QXD3500ZT	Count	20	0	20
	% within Type	100,0%	,0%	100,0%
QXD3570	Count	206	62	268
	% within Type	76,9%	23,1%	100,0%
QXD5370RDS	Count	613	73	686
	% within Type	89,4%	10,6%	100,0%
QXD537ORDS	Count	15	1	16
	% within Type	93,8%	6,3%	100,0%
TX3310	Count	24	1	25

	% within Type	96,0%	4,0%	100,0%
Total	Count	1685	681	2366
	% within Type	71,2%	28,8%	100,0%

Table 4.10.: Repair percentage for audio-sets

DVD-player			Repair department		Total
			Yes	No	
Type	ADR5800DI	Count	4	0	4
		% within Type	100,0%	,0%	100,0%
	DVP3410	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	DVP3470SK	Count	1	1	2
		% within Type	50,0%	50,0%	100,0%
	DVP3550S	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
	DVP4330S	Count	3	11	14
		% within Type	21,4%	78,6%	100,0%
	DVP4330SBOXF	Count	1	9	10
		% within Type	10,0%	90,0%	100,0%
	DVP4330SBOXN	Count	1	1	2
		% within Type	50,0%	50,0%	100,0%
	DVP4410	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	DVP4420S	Count	0	10	10
		% within Type	,0%	100,0%	100,0%
	DVP4420SBW	Count	1	5	6
		% within Type	16,7%	83,3%	100,0%
	DVP4420SBWCF	Count	0	2	2
		% within Type	,0%	100,0%	100,0%
	DVP4580SL	Count	81	46	127
		% within Type	63,8%	36,2%	100,0%
	DVP5380S	Count	86	19	105
		% within Type	81,9%	18,1%	100,0%
	DVP5380SBOXF	Count	9	11	20
		% within Type	45,0%	55,0%	100,0%
	DVP5380SBOXN	Count	92	11	103
		% within Type	89,3%	10,7%	100,0%
	DVP5388S	Count	42	31	73
		% within Type	57,5%	42,5%	100,0%
	DVPX7580	Count	18	22	40
		% within Type	45,0%	55,0%	100,0%
	DVX2880	Count	9	0	9
		% within Type	100,0%	,0%	100,0%
	EDX6100	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	NDV150	Count	11	63	74
		% within Type	14,9%	85,1%	100,0%
	NDV160	Count	57	248	305
		% within Type	18,7%	81,3%	100,0%
	NDV210	Count	3	6	9
		% within Type	33,3%	66,7%	100,0%

	NDV220	Count	25	49	74
		% within Type	33,8%	66,2%	100,0%
Total		Count	445	548	993
		% within Type	44,8%	55,2%	100,0%

Table 4.11.: Repair percentage for DVD-players

KTV DVD/Video combi			Repair department		Total
			Yes	No	
Type	CTR141MTV	Count	12	0	12
		% within Type	100,0%	,0%	100,0%
	CTR21MT4V	Count	5	1	6
		% within Type	83,3%	16,7%	100,0%
	CTS141MTD	Count	23	1	24
		% within Type	95,8%	4,2%	100,0%
	CTS141MTDE3	Count	126	14	140
		% within Type	90,0%	10,0%	100,0%
	CTS14MTDE3	Count	20	0	20
		% within Type	100,0%	,0%	100,0%
	CTS211MTD	Count	87	10	97
		% within Type	89,7%	10,3%	100,0%
	CTS21MTDE3	Count	80	3	83
		% within Type	96,4%	3,6%	100,0%
	DVV605N	Count	2	0	2
		% within Type	100,0%	,0%	100,0%
	DVV606N	Count	32	1	33
		% within Type	97,0%	3,0%	100,0%
	NDVCR300	Count	270	101	371
		% within Type	72,8%	27,2%	100,0%
	NTDV14	Count	114	27	141
		% within Type	80,9%	19,1%	100,0%
	NTDV21	Count	6	8	14
		% within Type	42,9%	57,1%	100,0%
Total		Count	777	166	943
		% within Type	82,4%	17,6%	100,0%

Table 4.12.: Repair percentage for KTV DVD/Video combi

Home Cinema			Repair department		Total
			Yes	No	
Type	AM810	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
	AX700	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
	AX810	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
	CMB4300SS	Count	13	0	13
		% within Type	100,0%	,0%	100,0%
	CX4200	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
	DRR5800PST	Count	20	2	22
		% within Type	90,9%	9,1%	100,0%
	DVR2120	Count	1	0	1

		% within Type	100,0%	,0%	100,0%
	DVR3100SS	Count	21	0	21
		% within Type	100,0%	,0%	100,0%
	DVR3100VSS	Count	12	0	12
		% within Type	100,0%	,0%	100,0%
	DVR3110SS	Count	5	0	5
		% within Type	100,0%	,0%	100,0%
	DVR3300SS	Count	7	0	7
		% within Type	100,0%	,0%	100,0%
	DVR3400SS	Count	35	2	37
		% within Type	94,6%	5,4%	100,0%
	DVR3500SS	Count	18	1	19
		% within Type	94,7%	5,3%	100,0%
	DVR4000SS	Count	154	4	158
		% within Type	97,5%	2,5%	100,0%
	DVR4000VSS	Count	5	1	6
		% within Type	83,3%	16,7%	100,0%
	DVR4100VSS	Count	27	5	32
		% within Type	84,4%	15,6%	100,0%
	DVR4100VSSCN	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
	DVR4200SS	Count	125	7	132
		% within Type	94,7%	5,3%	100,0%
	DVR4400SS	Count	75	4	79
		% within Type	94,9%	5,1%	100,0%
	DVR4400SSCNED	Count	22	3	25
		% within Type	88,0%	12,0%	100,0%
	DVR4410SS	Count	24	2	26
		% within Type	92,3%	7,7%	100,0%
	DVR4720SS	Count	88	6	94
		% within Type	93,6%	6,4%	100,0%
	NHTS300	Count	75	17	92
		% within Type	81,5%	18,5%	100,0%
	NHTS301	Count	15	3	18
		% within Type	83,3%	16,7%	100,0%
	SS4500	Count	1	6	7
		% within Type	14,3%	85,7%	100,0%
	STS22AAST10	Count	10	1	11
		% within Type	90,9%	9,1%	100,0%
	STS22AAST20	Count	28	2	30
		% within Type	93,3%	6,7%	100,0%
	STS22EAAST10	Count	30	1	31
		% within Type	96,8%	3,2%	100,0%
	STS22SAAST20	Count	10	0	10
		% within Type	100,0%	,0%	100,0%
	STS31AAST10	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
Total		Count	827	67	894
		% within Type	92,5%	7,5%	100,0%

Table 4.13.: Repair percentage for Home Cinema

CRT-television			Repair department		Total
			Yes	No	
Type	CTR141MTV	Count	12	0	12
		% within Type	100,0%	,0%	100,0%
	CTR21MT4V	Count	5	1	6
		% within Type	83,3%	16,7%	100,0%
	CTS141MTD	Count	23	1	24
		% within Type	95,8%	4,2%	100,0%
	CTS141MTDE3	Count	126	14	140
		% within Type	90,0%	10,0%	100,0%
	CTS14MTDE3	Count	20	0	20
		% within Type	100,0%	,0%	100,0%
	CTS211MTD	Count	87	10	97
		% within Type	89,7%	10,3%	100,0%
	CTS21MTDE3	Count	80	3	83
		% within Type	96,4%	3,6%	100,0%
	DVV605N	Count	2	0	2
		% within Type	100,0%	,0%	100,0%
	DVV606N	Count	32	1	33
		% within Type	97,0%	3,0%	100,0%
	NDVCR300	Count	270	101	371
		% within Type	72,8%	27,2%	100,0%
	NTDV14	Count	114	27	141
		% within Type	80,9%	19,1%	100,0%
	NTDV21	Count	6	8	14
		% within Type	42,9%	57,1%	100,0%
Total		Count	777	166	943
		% within Type	82,4%	17,6%	100,0%

Table 4.14.: Repair percentage for CRT-television

Discman			Repair department		Total
			Yes	No	
Type	DM820545	Count	0	7	7
		% within Type	,0%	100,0%	100,0%
	DM8700	Count	0	9	9
		% within Type	,0%	100,0%	100,0%
	DM8707	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	NPCD1045	Count	0	15	15
		% within Type	,0%	100,0%	100,0%
	NPCD10MP	Count	0	7	7
		% within Type	,0%	100,0%	100,0%
	PDP2300	Count	0	3	3
		% within Type	,0%	100,0%	100,0%
	PDP2300I	Count	1	4	5
		% within Type	20,0%	80,0%	100,0%
	PDP2300T	Count	1	15	16
		% within Type	6,3%	93,8%	100,0%
	PDP4000T	Count	0	24	24
		% within Type	,0%	100,0%	100,0%

	PDP4580SRBW	Count	11	119	130
		% within Type	8,5%	91,5%	100,0%
	PDP4580SROR	Count	0	28	28
		% within Type	,0%	100,0%	100,0%
	PDP4580SRZR	Count	13	103	116
		% within Type	11,2%	88,8%	100,0%
	PDX2210	Count	0	2	2
		% within Type	,0%	100,0%	100,0%
	PDX2210I	Count	6	66	72
		% within Type	8,3%	91,7%	100,0%
	PDX2210IMKIDS	Count	0	7	7
		% within Type	,0%	100,0%	100,0%
	PDX3780	Count	1	15	16
		% within Type	6,3%	93,8%	100,0%
	PDX4440	Count	1	0	1
		% within Type	100,0%	,0%	100,0%
	PDX4440R	Count	0	5	5
		% within Type	,0%	100,0%	100,0%
Total		Count	34	430	464
		% within Type	7,3%	92,7%	100,0%

Table 4.15.: Repair percentage for Discman

Alarmclock			Repair department		Total
			Yes	No	
Type	AR4100	Count	1	35	36
		% within Type	2,8%	97,2%	100,0%
	ARF360D	Count	0	117	117
		% within Type	,0%	100,0%	100,0%
	CD112AT	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	CD112GS	Count	0	5	5
		% within Type	,0%	100,0%	100,0%
	NCL7WT	Count	0	8	8
		% within Type	,0%	100,0%	100,0%
	NCL7ZR	Count	0	15	15
		% within Type	,0%	100,0%	100,0%
	NCR11ZR	Count	0	12	12
		% within Type	,0%	100,0%	100,0%
	NCR12WT	Count	0	57	57
		% within Type	,0%	100,0%	100,0%
	NCR12ZR	Count	0	2	2
		% within Type	,0%	100,0%	100,0%
	NCR24WT	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	NCR25ZR	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	NCR32ZR	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	NCR33WT	Count	0	26	26
		% within Type	,0%	100,0%	100,0%
	NCR33ZT	Count	0	36	36

		% within Type	,0%	100,0%	100,0%
	NCR35CD	Count	0	72	72
		% within Type	,0%	100,0%	100,0%
Total		Count	1	389	390
		% within Type	,3%	99,7%	100,0%

Table 4.16.: Repair percentage for Alarmclock

LCD-television			Repair department		Total
			Yes	No	
Type	AL1015	Count	23	3	26
		% within Type	88,5%	11,5%	100,0%
	AL1930	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	AL3210	Count	1	1	2
		% within Type	50,0%	50,0%	100,0%
	LMH17CLSA	Count	4	0	4
		% within Type	100,0%	,0%	100,0%
	LMH23CJSA	Count	18	5	23
		% within Type	78,3%	21,7%	100,0%
	LMH27CJSA	Count	68	1	69
		% within Type	98,6%	1,4%	100,0%
	LMH30CASA	Count	3	0	3
		% within Type	100,0%	,0%	100,0%
	LMH30CJBA	Count	8	1	9
		% within Type	88,9%	11,1%	100,0%
	LMH30CJSA	Count	31	0	31
		% within Type	100,0%	,0%	100,0%
	NL1550	Count	20	3	23
		% within Type	87,0%	13,0%	100,0%
Total		Count	176	15	191
		% within Type	92,1%	7,9%	100,0%

Table 4.17.: Repair percentage for LCDtv

VCR			Repair department		Total
			Yes	No	
Type	VSK206	Count	3	1	4
		% within Type	75,0%	25,0%	100,0%
	VSK207M	Count	39	7	46
		% within Type	84,8%	15,2%	100,0%
	VSK606	Count	3	2	5
		% within Type	60,0%	40,0%	100,0%
	VSK607N	Count	43	23	66
		% within Type	65,2%	34,8%	100,0%
Total		Count	88	33	121
		% within Type	72,7%	27,3%	100,0%

Table 4.18.: Repair percentage for VCR

Radio			Repair department		Total
			Yes	No	
Type	ADTS06	Count	4	24	28
		% within Type	14,3%	85,7%	100,0%

	ARP420RD	Count	0	2	2
		% within Type	,0%	100,0%	100,0%
	ARP420ZT	Count	0	17	17
		% within Type	,0%	100,0%	100,0%
	CMR15	Count	0	7	7
		% within Type	,0%	100,0%	100,0%
	NMR10ZR	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	NMR10ZRGB	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	NMR12	Count	0	8	8
		% within Type	,0%	100,0%	100,0%
	NMR12ZR	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
	NR3CHAMPIONOR	Count	0	3	3
		% within Type	,0%	100,0%	100,0%
	NR3ESOR	Count	0	1	1
		% within Type	,0%	100,0%	100,0%
Total		Count	4	65	69
		% within Type	5,8%	94,2%	100,0%

Table 4.19.: Repair percentage for Radio

4.5.15 LCDtv DVD/Video combi

LCDtv DVD/ Video combi			Repair department		Total
			Yes	No	
Type	ALD1900	Count	2	2	4
		% within Type	50,0%	50,0%	100,0%
	ALD1930X	Count	4	4	8
		% within Type	50,0%	50,0%	100,0%
	LT1509E	Count	6	4	10
		% within Type	60,0%	40,0%	100,0%
	LT2007E	Count	4	1	5
		% within Type	80,0%	20,0%	100,0%
Total		Count	16	11	27
		% within Type	59,3%	40,7%	100,0%

Table 4.20.: Repair percentage for LCDtv DVD/Video combi

PMR			Repair department	Total
			No	
Type	PMR1102	Count	2	2
		% within Type	100,0%	100,0%
	PMR1402	Count	3	3
		% within Type	100,0%	100,0%
Total		Count	5	5
		% within Type	100,0%	100,0%

Table 4.21.: Repair percentage for PMR

Appendix 4.3: Number of repaired warranty returns

4.3.1. Number of repaired warranty returns per month in 2006

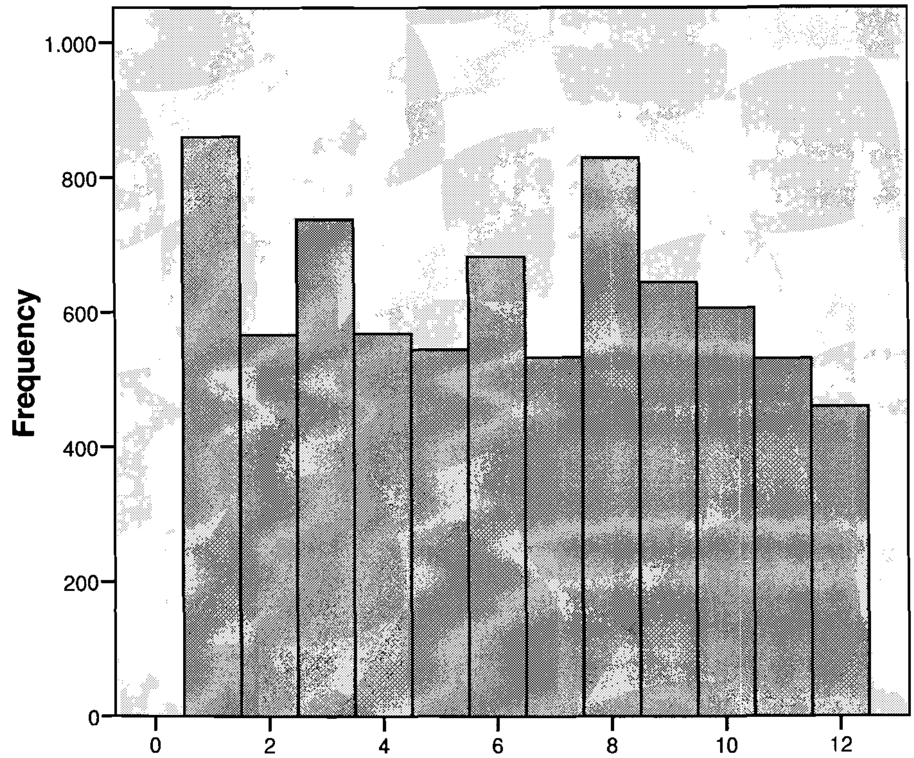


Fig. 4.13. The frequency of repair under warranty per month, month 1 starts 1 February

Appendix 4.4: The failure behavior of to be repaired warranty returns

4.4.1. Failure behavior combinations for the product groups

The tables below show the combination of failure section, type of failure and type of repair as expressed in the IRIS-codes. The codes displayed consist of the three IRIS-code parts joined together. The IRIS-code classification table is shown in Appendix 3.1. When codes that are only observed three or less times and together are responsible for less then 35% of the returns they are grouped under other.

The colums in the tables, from left to right, indicate the IRIScode, the frequency that it was observed, the percentage of the total number of observations for the product group and the cumulative percentage of the total repairs accounted for.

Audio-set		Frequency	Percent	Cumulative Percent
IRIScode:	DDMNA	277	16,4	16,4
	PSUNA	119	7,1	23,5
	SYSOL	105	6,2	29,7
	DDM3M	97	5,8	35,5
	DDMOA	87	5,2	40,7
	APDNA	72	4,3	44,9
	DDMCB	58	3,4	48,4
	SYSOA	57	3,4	51,8

	APA3M	34	2,0	53,8
	PSU3M	29	1,7	55,5
	03L	28	1,7	57,2
	DDM2Z	24	1,4	58,6
	DDM3L	23	1,4	59,9
	IDSNA	22	1,3	61,2
	REM0A	22	1,3	62,6
	APANA	21	1,2	63,8
	CTRNA	21	1,2	65,0
	SYS0C	20	1,2	66,2
	APD2A	18	1,1	67,3
	SYS2A	16	,9	68,2
	PSU0A	15	,9	69,1
	TDMNA	15	,9	70,0
	HFS3M	12	,7	70,7
	PSU2G	12	,7	71,5
	TDM0A	12	,7	72,2
	DDMNZ	11	,7	72,8
	00A	10	,6	73,4
	APA0A	10	,6	74,0
	HFSRD	10	,6	74,6
	SYSID	10	,6	75,2
	SYSPC	10	,6	75,8
	APARD	9	,5	76,3
	REMNA	9	,5	76,9
	0NA	8	,5	77,3
	APA2A	8	,5	77,8
	DDMBE	8	,5	78,3
	IDS0A	8	,5	78,8
	IDS3M	8	,5	79,2
	PSU0G	8	,5	79,7
	DDMCA	7	,4	80,1
	DDMDA	7	,4	80,5
	SYS0G	7	,4	80,9
	TUN3L	7	,4	81,4
	03M	6	,4	81,7
	DDM1Z	6	,4	82,1
	DDMTD	6	,4	82,4
	HFSNA	6	,4	82,8
	PSUID	6	,4	83,1
	TDMCB	6	,4	83,5
	APA2Z	5	,3	83,8
	CBT0A	5	,3	84,1
	CBTDA	5	,3	84,4

	DPRNA	5	,3	84,7
	MEMNA	5	,3	85,0
	PSU2A	5	,3	85,3
	SYSIC	5	,3	85,6
	02A	4	,2	85,8
	ONZ	4	,2	86,1
	DDM2A	4	,2	86,3
	DDMCH	4	,2	86,5
	DDMRD	4	,2	86,8
	SYS1A	4	,2	87,0
	SYS4L	4	,2	87,2
	TDMDA	4	,2	87,5
	TUN0A	4	,2	87,7
	TUNID	4	,2	88,0
	Other	203	12,0	100,0
	Total	1685	100,0	

Table 4.22: Audio-sets failure classification

Discman		Frequency	Percent	Cumulative Percent
IRIScode:	SYS0A	11	32,4	32,4
	03L	8	23,5	55,9
	00L	4	11,8	67,6
	other	11	32,4	100,0

Table 4.23: Discman failure classification

DVD-player		Frequency	Percent	Cumulative Percent
IRIScode:	PSUNA	55	12,4	12,4
	DDMNA	46	10,3	22,7
	SYSNA	35	7,9	30,6
	DDM3M	33	7,4	38,0
	SYS0A	23	5,2	43,1
	REM0A	21	4,7	47,9
	SYS0L	18	4,0	51,9
	03L	15	3,4	55,3
	REMNA	13	2,9	58,2
	DDMCB	12	2,7	60,9
	SYS4L	12	2,7	63,6
	APR3M	10	2,2	65,8
	03M	8	1,8	67,6
	00A	7	1,6	69,2
	PSU0G	7	1,6	70,8
	SYS2A	7	1,6	72,4
	APA3M	6	1,3	73,7

	DDM0A	6	1,3	75,1
	04L	5	1,1	76,2
	CBTCB	5	1,1	77,3
	DDM2Z	5	1,1	78,4
	PSU2A	5	1,1	79,6
	PSU3M	5	1,1	80,7
	REM2A	5	1,1	81,8
	Other	81	18,2	100,0
	Total	445	100,0	

Table 4.24: DVD-player failure classification

Home-cinema		Frequency	Percent	Cumulative Percent
IRIScode:	DDMNA	196	23,7	23,7
	DDM3M	47	5,7	29,4
	SYS0L	47	5,7	35,1
	03L	44	5,3	40,4
	APA3M	43	5,2	45,6
	DDM0A	43	5,2	50,8
	PSUNA	41	5,0	55,7
	03M	22	2,7	58,4
	APANA	20	2,4	60,8
	SYS0A	19	2,3	63,1
	SYSNA	19	2,3	65,4
	DDM3L	16	1,9	67,4
	0NA	12	1,5	68,8
	APA4L	10	1,2	70,0
	DDM2A	10	1,2	71,2
	DDMCB	10	1,2	72,4
	04L	9	1,1	73,5
	SYS4L	9	1,1	74,6
	REMNA	7	,8	75,5
	CTRNA	6	,7	76,2
	APA3L	5	,6	76,8
	HFSNA	5	,6	77,4
	PWA3L	5	,6	78,0
	REM0A	5	,6	78,6
	SPKNA	5	,6	79,2
	SYS0C	5	,6	79,8
	SYS2A	5	,6	80,4
	APA2Z	4	,5	80,9
	PSU3M	4	,5	81,4
	SPK3L	4	,5	81,9
	SYSPC	4	,5	82,3

	Other	143	17,7	100
	Total	827	100,0	

Table 4.25: Home-cinema failure classification

CRT DVD/ Video combi		Frequency	Percent	Cumulative Percent
IRIScode:	DDMNA	198	25,5	25,5
	PSUNA	97	12,5	38,0
	DDM3M	68	8,8	46,7
	03L	55	7,1	53,8
	DDM3L	50	6,4	60,2
	SYS0L	31	4,0	64,2
	DDMBE	21	2,7	66,9
	REMNA	20	2,6	69,5
	SYS4L	18	2,3	71,8
	PSU3M	15	1,9	73,7
	TDM3M	14	1,8	75,5
	0NA	12	1,5	77,1
	DDMCB	10	1,3	78,4
	CTRNA	9	1,2	79,5
	SYS0A	8	1,0	80,6
	DFLNA	7	,9	81,5
	TDMNA	6	,8	82,2
	04L	5	,6	82,9
	0NZ	5	,6	83,5
	DDM0A	5	,6	84,2
	HFSNA	5	,6	84,8
	REM2A	5	,6	85,5
	00A	4	,5	86,0
	HFS3M	4	,5	86,5
	TDMCB	4	,5	87,0
	Other	101	13,0	100,0
	Total	777	100,0	

Table 4.26: CRT DVD/video combi failure classification

CRT-television		Frequency	Percent	Cumulative Percent
IRIScode:	PSUNA	145	23,6	23,6
	03L	37	6,0	29,6
	SYS0L	30	4,9	34,5
	0NA	26	4,2	38,7
	DFLNA	21	3,4	42,1
	PSU3M	17	2,8	44,9
	REMNA	16	2,6	47,5
	PSU2A	12	2,0	49,4

	SYS2A	12	2,0	51,4
	APA3M	11	1,8	53,2
	CPANA	11	1,8	55,0
	PSU0G	11	1,8	56,7
	PSUID	11	1,8	58,5
	SYSPC	11	1,8	60,3
	DFL3M	10	1,6	62,0
	PSU2G	10	1,6	63,6
	REM0A	10	1,6	65,2
	SYS0A	10	1,6	66,8
	SYS0C	10	1,6	68,5
	APANA	9	1,5	69,9
	DFLCB	7	1,1	71,1
	HFSNA	7	1,1	72,2
	SYS1C	7	1,1	73,3
	PSU0D	6	1,0	74,3
	SYS1A	6	1,0	75,3
	APA2A	5	,8	76,1
	CPA3M	5	,8	76,9
	HFS3M	5	,8	77,7
	PSU0A	5	,8	78,5
	PSURD	5	,8	79,3
	02A	4	,7	80,0
	APA0A	4	,7	80,7
	APAPG	4	,7	81,3
	TUNNA	4	,7	82,0
	Other	111	18,0	100,0
	Total	615	100,0	

Table 4.27: CRT-television failure classification

LCDtv DVD/ Video combi		Frequency	Percent	Cumulative Percent
IRIScode:	03L	3	18,8	18,8
	DDMNA	3	18,8	37,5
	04L	1	6,3	43,8
	0NZ	1	6,3	50,0
	ANT1Z	1	6,3	56,3
	APANZ	1	6,3	62,5
	DDM00	1	6,3	68,8
	DDM1Z	1	6,3	75,0
	DDM3M	1	6,3	81,3
	HFS3M	1	6,3	87,5
	PSU3M	1	6,3	93,8
	SYS01	1	6,3	100,0
	Total	16	100,0	

Table 4.28: LCDtv DVD combi failure classification

LCD-television		Frequency	Percent	Cumulative Percent
IRIScode:	PSUNA	61	34,7	34,7
	03L	23	13,1	47,7
	0NA	15	8,5	56,3
	PSU0A	13	7,4	63,6
	IMG3M	8	4,5	68,2
	SYS0L	8	4,5	72,7
	IMG2Z	4	2,3	75,0
	SFT0A	3	1,7	76,7
	00A	2	1,1	77,8
	03M	2	1,1	79,0
	0TD	2	1,1	80,1
	CPA3M	2	1,1	81,3
	DDMNA	2	1,1	82,4
	IMGNA	2	1,1	83,5
	PSU2A	2	1,1	84,7
	PSU3M	2	1,1	85,8
	SFT1A	2	1,1	86,9
	SYS1A	2	1,1	88,1
	03Q	1	,6	88,6
	0NQ	1	,6	89,2
	0RD	1	,6	89,8
	APR3M	1	,6	90,3
	CPANA	1	,6	90,9
	CPARD	1	,6	91,5
	CPDNA	1	,6	92,0
	CTR2A	1	,6	92,6
	CTR3M	1	,6	93,2
	CTRNA	1	,6	93,8
	IMGCB	1	,6	94,3
	IMGNZ	1	,6	94,9
	PSU0L	1	,6	95,5
	PSU2Z	1	,6	96,0
	PSU3L	1	,6	96,6
	REM0A	1	,6	97,2
	REMNA	1	,6	97,7
	SFTNA	1	,6	98,3
	SYS0A	1	,6	98,9
	SYS3Q	1	,6	99,4
	SYSIH	1	,6	100,0
	Total	176	100,0	

Table 4.29: LCDtv failure classification

MP3-player		Frequency	Percent	Cumulative Percent
IRIScode:	03L	247	65,2	65,2

	SYS0A	55	14,5	79,7
	SYS0L	17	4,5	84,2
	IDS0A	12	3,2	87,3
	SYS0C	7	1,8	89,2
	00L	6	1,6	90,8
	02A	6	1,6	92,3
	Other	29	7,7	100,0
	Total	379	100,0	

Table 4.30: MP3 player failure classification

Portable LCD DVD player		Frequency	Percent	Cumulative Percent
IRIScode:	DDM0A	259	11,5	11,5
	SYS0L	250	11,1	22,5
	SYS0A	217	9,6	32,1
	DDMNA	144	6,4	38,5
	IDS0A	140	6,2	44,7
	PSUNA	126	5,6	50,2
	DDMCB	91	4,0	54,2
	PSU0A	58	2,6	56,8
	DDM3M	57	2,5	59,3
	SYS4L	54	2,4	61,7
	DDMBE	53	2,3	64,1
	IMGNA	42	1,9	65,9
	IDSNA	38	1,7	67,6
	SYS0C	35	1,5	69,1
	PSU2A	30	1,3	70,5
	PSU3M	30	1,3	71,8
	EXC0A	28	1,2	73,0
	IDS3M	26	1,1	74,2
	PSU0G	24	1,1	75,2
	SYS2A	20	,9	76,1
	REM0A	19	,8	77,0
	0NA	18	,8	77,8
	DDM0B	18	,8	78,6
	DDM0E	15	,7	79,2
	IMG3M	15	,7	79,9
	DDM1A	14	,6	80,5
	PSU2G	13	,6	81,1
	IDS2A	12	,5	81,6
	SYS0G	12	,5	82,1
	00A	11	,5	82,6
	CBT0A	11	,5	83,1

		Frequency	Percent	Cumulative Percent
	DDM2Z	11	,5	83,6
	02A	10	,4	84,0
	IDS0G	10	,4	84,5
	SYSCB	10	,4	84,9
	DDMIC	8	,4	85,3
	SYS1C	8	,4	85,6
	SYSIC	8	,4	86,0
	SYSPC	8	,4	86,3
	APA0A	7	,3	86,6
	CTRNA	7	,3	87,0
	DDM2A	7	,3	87,3
	DDM0C	6	,3	87,5
	DDM3L	6	,3	87,8
	DDMCC	6	,3	88,1
	IDS0L	6	,3	88,3
	IMG2A	6	,3	88,6
	03L	5	,2	88,8
	APR3M	5	,2	89,0
	EXC0K	5	,2	89,3
	SYS2C	5	,2	89,5
	03M	4	,2	89,7
	APA2A	4	,2	89,8
	CBTDA	4	,2	90,0
	CPA3M	4	,2	90,2
	DDM0L	4	,2	90,4
	DDMFB	4	,2	90,5
	DDMIG	4	,2	90,7
	IDS2G	4	,2	90,9
	IMG2Z	4	,2	91,1
	PSU0D	4	,2	91,2
	PSUID	4	,2	91,4
	SYS00	4	,2	91,6
	SYS0K	4	,2	91,8
	SYSID	4	,2	92,0
	Other	181	8,0	100,0
	Total	2262	100,0	

Table 4.31: Portable LCD DVD player failure classification

Portable Radio/ CD player		Frequency	Percent	Cumulative Percent
IRIScode:	DDMNA	60	23,8	23,8
	SYS0L	18	7,1	31,0

	03L	14	5,6	36,5
	SYS0A	13	5,2	41,7
	DDM3M	12	4,8	46,4
	DDM3L	9	3,6	50,0
	PSUNA	7	2,8	52,8
	DDM0A	6	2,4	55,2
	DDM2Z	6	2,4	57,5
	DDM2A	5	2,0	59,5
	02A	4	1,6	61,1
	DDMCB	4	1,6	62,7
	02Z	3	1,2	63,9
	0NA	3	1,2	65,1
	ANTDA	3	1,2	66,3
	DDMDA	3	1,2	67,5
	TDM2Z	3	1,2	68,7
	TDM3M	3	1,2	69,8
	Other	76	30,2	100,0
	Total	252	100,0	

Table 4.32: Portable RacioCD player failure classification

VCR		Frequency	Percent	Cumulative Percent
IRIScode:	TDM3M	24	27,3	27,3
	TDMNA	13	14,8	42,0
	TDMCB	12	13,6	55,7
	TDMBE	11	12,5	68,2
	Other	28	31,8	100,0
	Total	88	100,0	

Table 4.33: VCR failure classification

Aggregate figures		Frequency	Percent	Cumulative Percent
IRIScode:	DDMNA	926	12,2	12,2
	PSUNA	655	8,7	20,9
	SYS0L	529	7,0	27,9
	03L	483	6,4	34,2
	SYS0A	415	5,5	39,7
	DDM0A	409	5,4	45,1
	DDM3M	315	4,2	49,3
	DDMCB	186	2,5	51,8
	IDS0A	162	2,1	53,9
	DDM3L	106	1,4	55,3
	PSU3M	105	1,4	56,7
	SYS4L	101	1,3	58,0

	APA3M	99	1,3	59,3
	0NA	97	1,3	60,6
	PSU0A	94	1,2	61,8
	DDMBE	87	1,1	63,0
	REM0A	84	1,1	64,1
	SYS0C	83	1,1	65,2
	APDNA	76	1,0	66,2
	REMNA	67	,9	67,1
	IDSNA	63	,8	67,9
	SYS2A	63	,8	68,7
	SYSNA	61	,8	69,6
	PSU2A	58	,8	70,3
	PSU0G	55	,7	71,0
	APANA	54	,7	71,8
	DDM2Z	52	,7	72,4
	CTRNA	50	,7	73,1
	IMGNA	48	,6	73,7
	03M	46	,6	74,3
	TDM3M	44	,6	74,9
	00A	38	,5	75,4
	IDS3M	37	,5	75,9
	PSU2G	36	,5	76,4
	TDMNA	35	,5	76,9
	SYSPC	34	,4	77,3
	EXC0A	31	,4	77,7
	02A	30	,4	78,1
	04L	30	,4	78,5
	DDM2A	30	,4	78,9
	PSUID	29	,4	79,3
	DFLNA	28	,4	79,7
	IMG3M	26	,3	80,0
	HFS3M	25	,3	80,3
	APA0A	24	,3	80,6
	HFSNA	24	,3	81,0
	DDM0B	23	,3	81,3
	SYS0G	23	,3	81,6
	TDMCB	22	,3	81,9
	APD2A	21	,3	82,1
	APR3M	21	,3	82,4
	APA2A	20	,3	82,7
	0NZ	19	,3	82,9
	CBT0A	19	,3	83,2

	SYS1C	19	,3	83,4
	SYSID	19	,3	83,7
	DDMNZ	18	,2	83,9
	TDMBE	18	,2	84,2
	CPA3M	17	,2	84,4
	DDM1A	17	,2	84,6
	DDM0E	16	,2	84,8
	SYSIC	15	,2	85,0
	02Z	14	,2	85,2
	CPANA	14	,2	85,4
	DDMDA	14	,2	85,6
	REM2A	14	,2	85,8
	SYS1A	14	,2	85,9
	00L	13	,2	86,1
	APARD	13	,2	86,3
	DDMCA	13	,2	86,5
	DDMFB	13	,2	86,6
	IDS2A	13	,2	86,8
	TDM0A	13	,2	87,0
	DFL3M	12	,2	87,1
	PSU0D	12	,2	87,3
	PSU3L	12	,2	87,5
	TUN3L	12	,2	87,6
	APA2Z	11	,1	87,8
	CTR3M	11	,1	87,9
	HFSRD	11	,1	88,0
	IDS0G	11	,1	88,2
	PSU2Z	11	,1	88,3
	SPKNA	11	,1	88,5
	APA4L	10	,1	88,6
	DDM0L	10	,1	88,7
	SYSCB	10	,1	88,9
	CBTCB	9	,1	89,0
	CBTDA	9	,1	89,1
	DDM1Z	9	,1	89,2
	DDMIC	9	,1	89,4
	PSURD	9	,1	89,5
	PWA3L	9	,1	89,6
	IMG2Z	8	,1	89,7
	SFT0A	8	,1	89,8
	TDM2Z	8	,1	89,9
	DDM0C	7	,1	90,0

DDMCH	7	,1	90,1
DFLCB	7	,1	90,2
IDS0L	7	,1	90,3
IMG2A	7	,1	90,4
REM0L	7	,1	90,5
REM3L	7	,1	90,6
SFTNA	7	,1	90,6
SYS00	7	,1	90,7
SYS2C	7	,1	90,8
TUNNA	7	,1	90,9
APA3L	6	,1	91,0
APD0A	6	,1	91,1
DDMCC	6	,1	91,2
DDMRD	6	,1	91,2
DDMTD	6	,1	91,3
DPRNA	6	,1	91,4
SYS0B	6	,1	91,5
TDMDA	6	,1	91,6
TUN0A	6	,1	91,6
03P	5	,1	91,7
APD2Z	5	,1	91,8
APD3M	5	,1	91,8
CTR0A	5	,1	91,9
DDM0H	5	,1	92,0
DDM2B	5	,1	92,0
DDM4L	5	,1	92,1
DDMID	5	,1	92,2
DDMIG	5	,1	92,2
DPR3M	5	,1	92,3
EXC0K	5	,1	92,4
HFSDA	5	,1	92,4
MEMNA	5	,1	92,5
PSU0C	5	,1	92,6
PSUTD	5	,1	92,6
PWATD	5	,1	92,7
SYS0K	5	,1	92,8
SYSPG	5	,1	92,8
TDM3L	5	,1	92,9
0DA	4	,1	92,9
ANTDA	4	,1	93,0
APANZ	4	,1	93,1
APAPG	4	,1	93,1

	CBT0B	4	,1	93,2
	CPARD	4	,1	93,2
	DDM3P	4	,1	93,3
	DDMFH	4	,1	93,3
	HFS2Z	4	,1	93,4
	IDS0C	4	,1	93,4
	IDS2G	4	,1	93,5
	PSU0L	4	,1	93,5
	PSUNZ	4	,1	93,6
	PWANA	4	,1	93,6
	REM00	4	,1	93,7
	SFT1A	4	,1	93,7
	SFT2A	4	,1	93,8
	SPK3L	4	,1	93,8
	SPKTD	4	,1	93,9
	SYS0D	4	,1	94,0
	SYS0E	4	,1	94,0
	TDMCA	4	,1	94,1
	TUNID	4	,1	94,1
	Other	447	5,9	100,0
	Total	7571	100,0	

Table 4.34: Aggregate figures failure classification

4.4.2 The failure behavior of out-of-warranty returns

Aggregate figures		Frequency	Percent	Cumulative Percent
IRIScode:	DDMNA	131	14,3	14,3
	XXXDV	60	6,6	20,9
	PSUNA	59	6,5	27,4
	DDM0A	51	5,6	32,9
	PSUKV	50	5,5	38,4
	02Z	36	3,9	42,3
	02V	31	3,4	45,7
	DDM2V	26	2,8	48,6
	00V	24	2,6	51,2
	SYS0A	24	2,6	53,8
	DDMNV	21	2,3	56,1
	PSUKZ	18	2,0	58,1
	0NA	15	1,6	59,7
	PSU2G	15	1,6	61,4
	IDS0A	13	1,4	62,8
	IMGDV	12	1,3	64,1

	SYS2V	12	1,3	65,4
	XXXDZ	11	1,2	66,6
	DDM2A	10	1,1	67,7
	00A	9	1,0	68,7
	00Y	9	1,0	69,7
	PSU0A	9	1,0	70,7
	03L	8	,9	71,6
	PSU2A	8	,9	72,4
	TUNNA	7	,8	73,2
	XXXGZ	7	,8	74,0
	PSUNV	6	,7	74,6
	SYS2Z	6	,7	75,3
	XXXGV	6	,7	75,9
	DDM2Z	5	,5	76,5
	DDMDV	5	,5	77,0
	IMGDZ	5	,5	77,6
	SYS0Y	5	,5	78,1
	TDMNA	5	,5	78,7
	0DV	4	,4	79,1
	0KV	4	,4	79,5
	CBT2A	4	,4	80,0
	CBTDA	4	,4	80,4
	DVD2V	4	,4	80,9
	HFSNA	4	,4	81,3
	SYS2A	4	,4	81,7
	SYSKV	4	,4	82,2
	Other	163	17,8	100,0
	Total	914	100,0	

Table 4.35: Out of warranty failure classification

Appendix 12

In this Appendix the models used in the simulation are displayed. The graphic representation of the models is displayed in Appendix 12.1 to 12.3. The arrival page is identical for all three designs. The repair page is identical for design 1 and 2. Both are shown in Appendix 12.1. Appendix 12.4 contains the declarations used in the models. These declaration were varied between models to obtain the simulated scenarios. The variations are available at the author upon request.
The used symbols in the figures representing the following:

Ellipses:
Places, in a place something is stored. This something can be a person or product or administrative object, value etc. Each place can store certain things, depending on how the place is defined. This way eg persons do not get mixed with products.

Squares:
Transitions, a transition performs an action. To do so it requires objects from places. After the action objects are sent to the same or other places for storage agains. The action can represent anything from the periodic calculation of a formula to the transport or repair of a product. The actions can only be performed if the right objects for the action are in the places connected to the transition. With the action also a time delay can be defined.

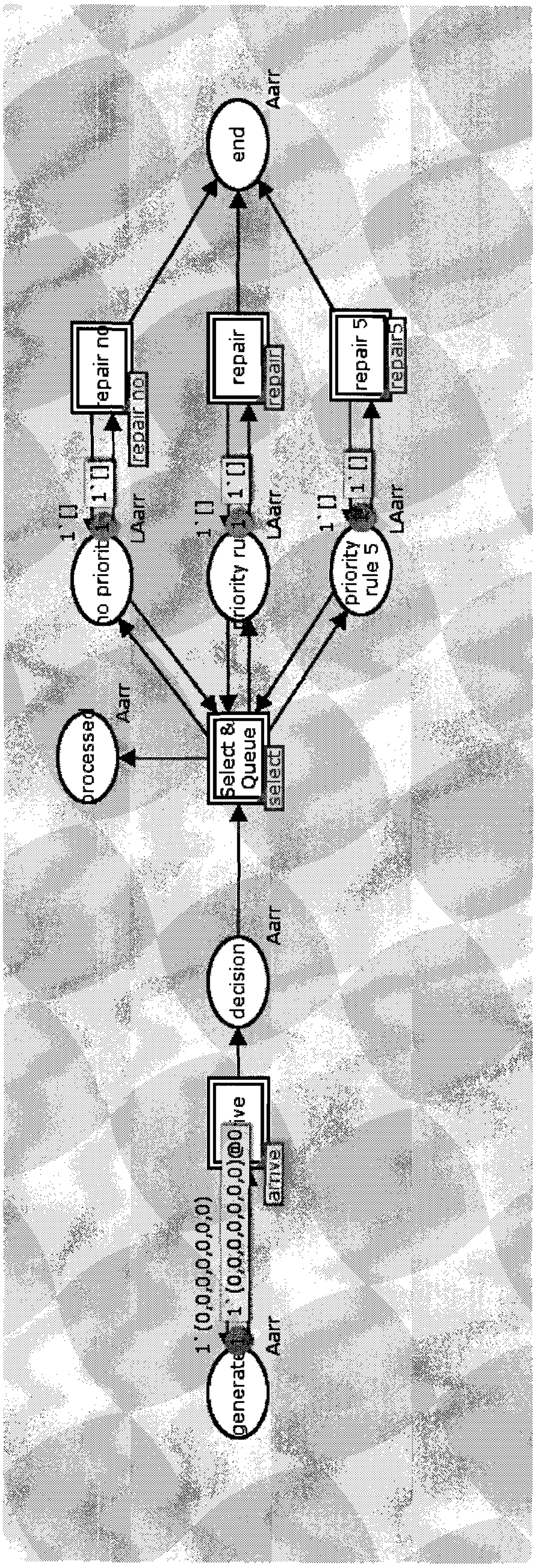
Arrows:
Arrows connect the places with the transitions, on the arrows it is defined what goes in transitions and what comes out of them and in which place it is then stored again.

Declarations:
In the declarations all variables and formula's are defined. The abbreviations used for places, transitions and arrows are defined there.

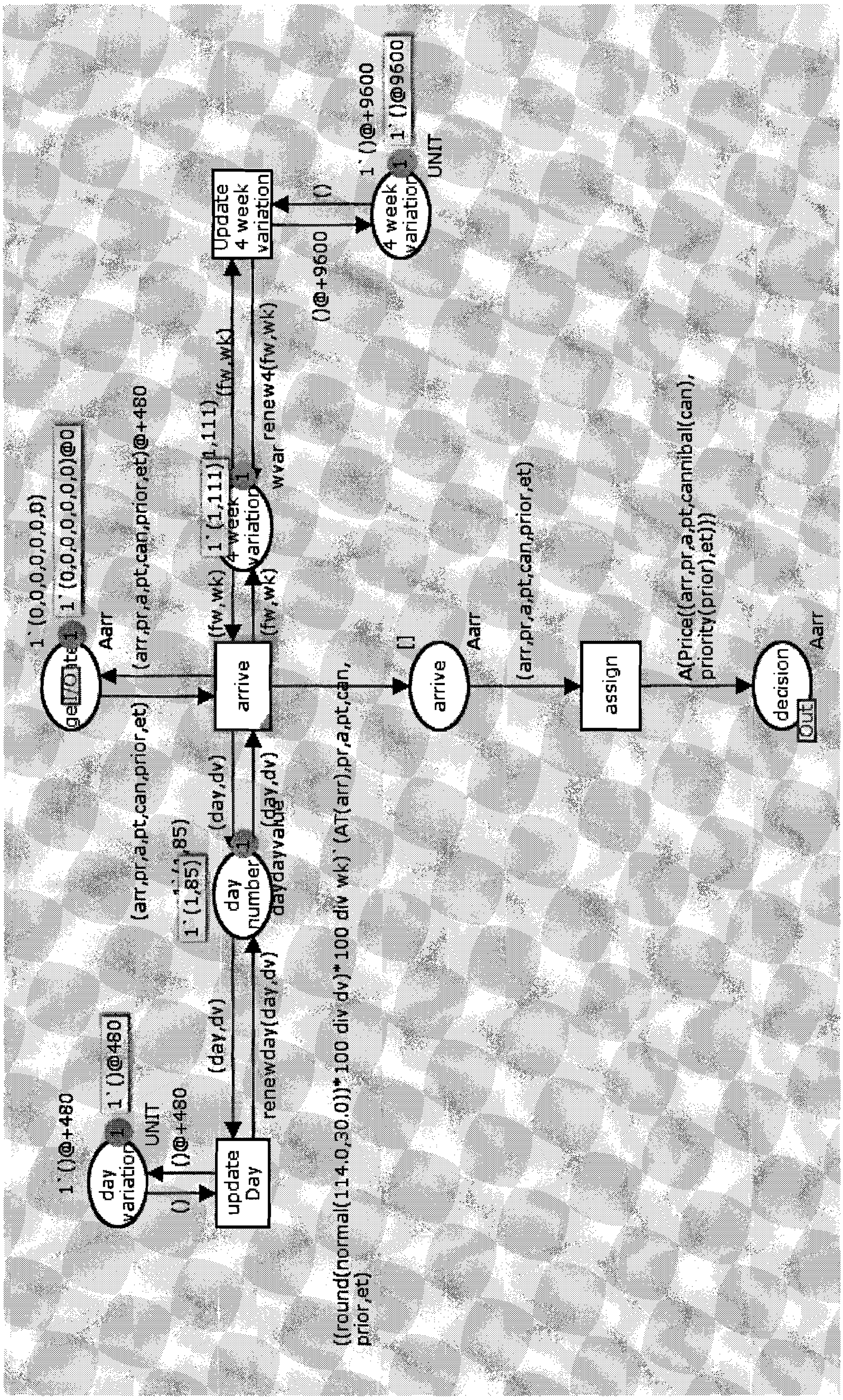
Hierarchy: super and subpages
To allow for a complex model to be readable the concept of hierarchy is used. With this concept several transitions and places can be displayed as one transition. This transition then represents the underlying structure on the superpage, whilst the structure of places and transitions is shown on the subpage.

Appendix 12.1. Design 1

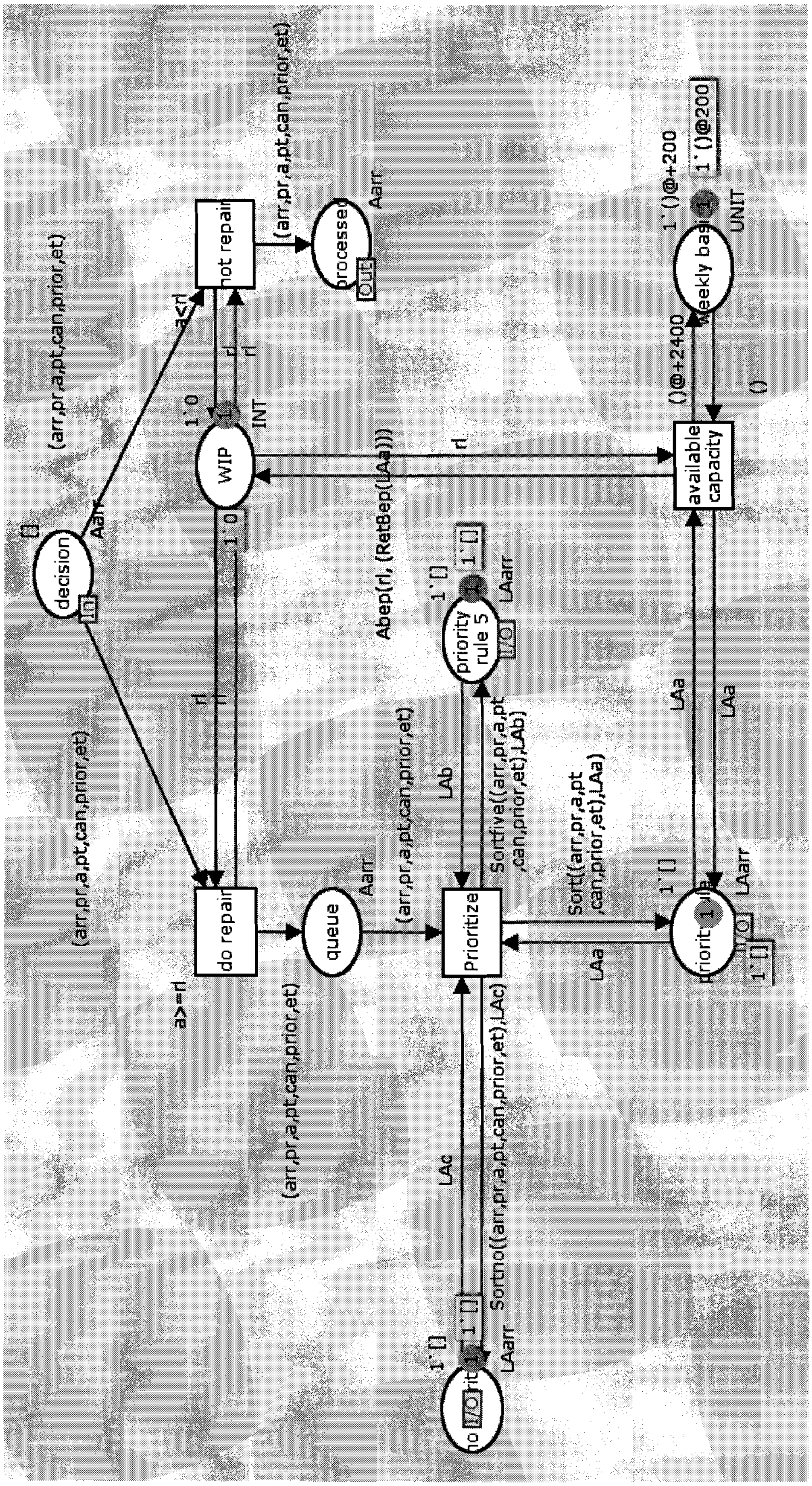
Appendix 12.1.1. The total model (superpage)



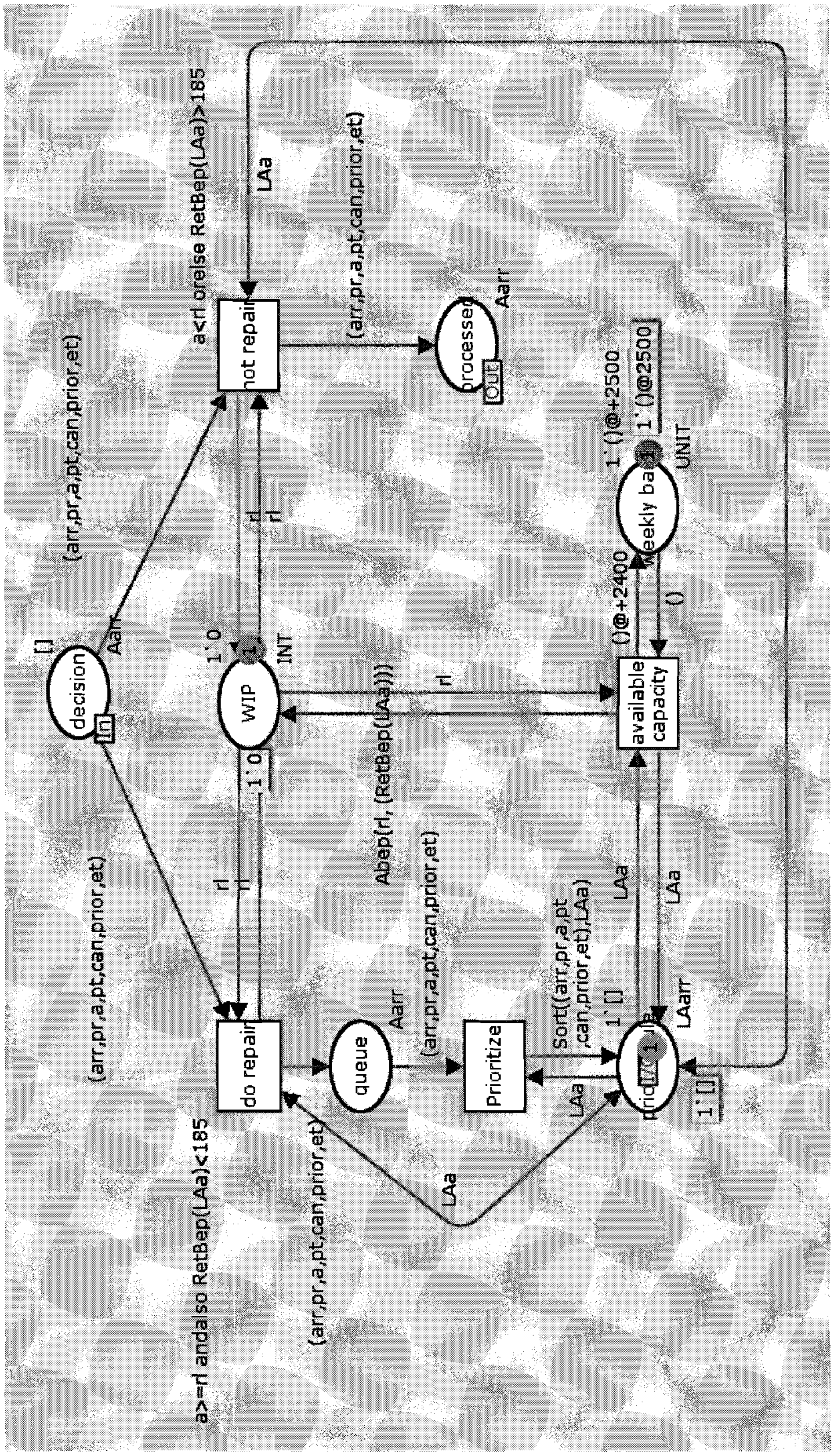
Appendix 12.1.2. Arrive (subpage)



Appendix 12.1.3: Select (subpage)



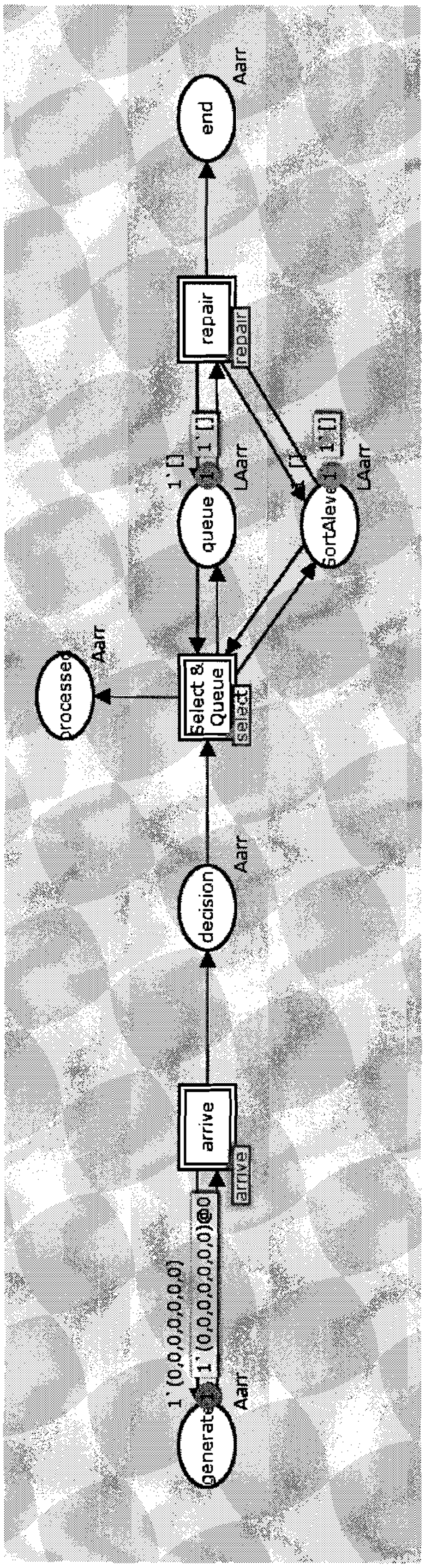
12.2.2: Select

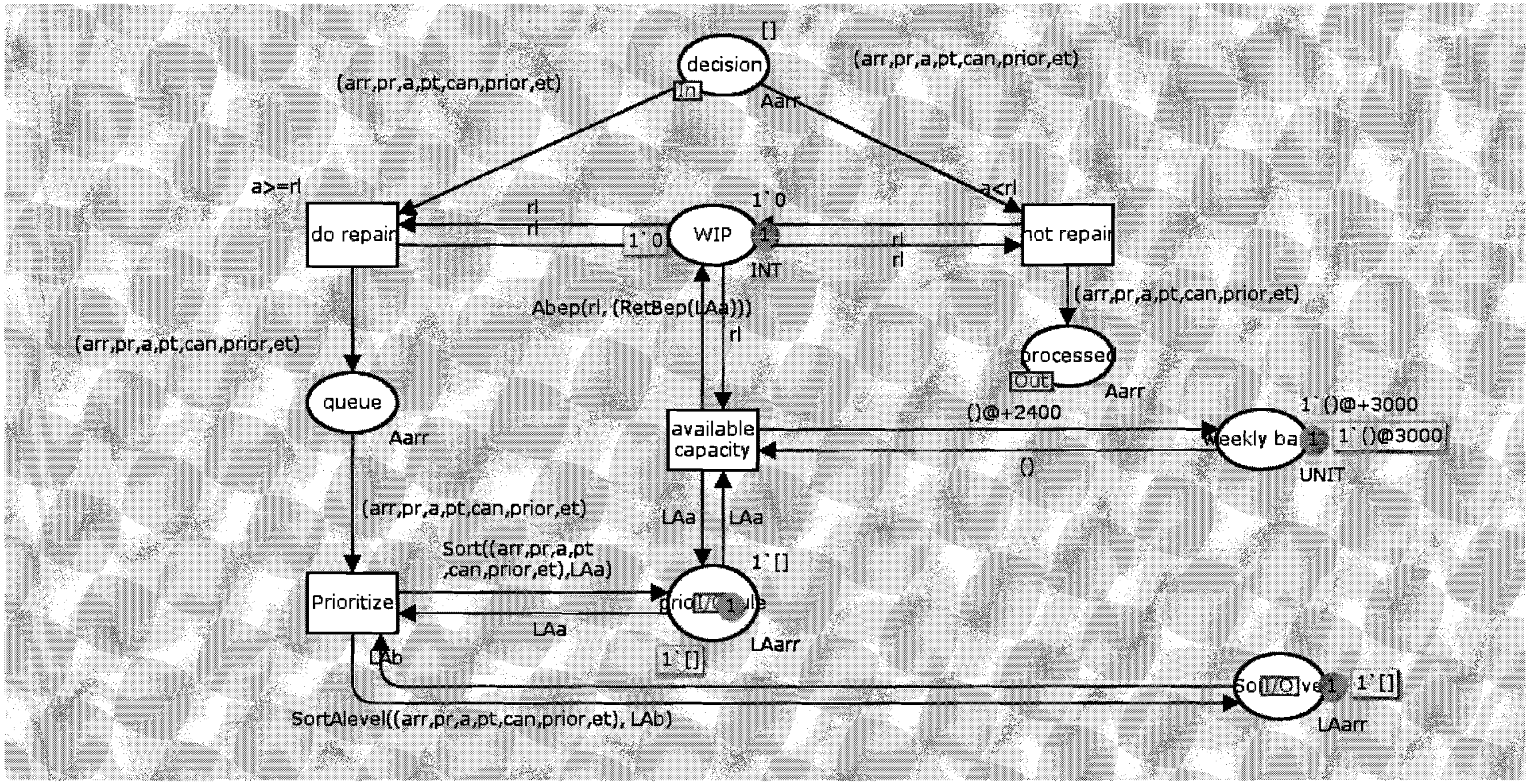


decision
In
[]
Aarr
(arr,pr,a,pt,can,prior,et)
a<rl orelse RetBep(LAa)>185
LAa
(arr,pr,a,pt,can,prior,et)
Out
Aarr
1`()@+2500
1`()@2500
UNIT
()@+2400
()
available capacity
rl
rl
WIP
1`0
INT
Abep(rl, (RetBep(LAa)))
(arr,pr,a,pt,can,prior,et)
queue
Aarr
(arr,pr,a,pt,can,prior,et)
Prioritize
Sort((arr,pr,a,pt,can,prior,et),LAa)
LAa
LAa
LAarr
1`[]
a>=rl andalso RetBep(LAa)<185

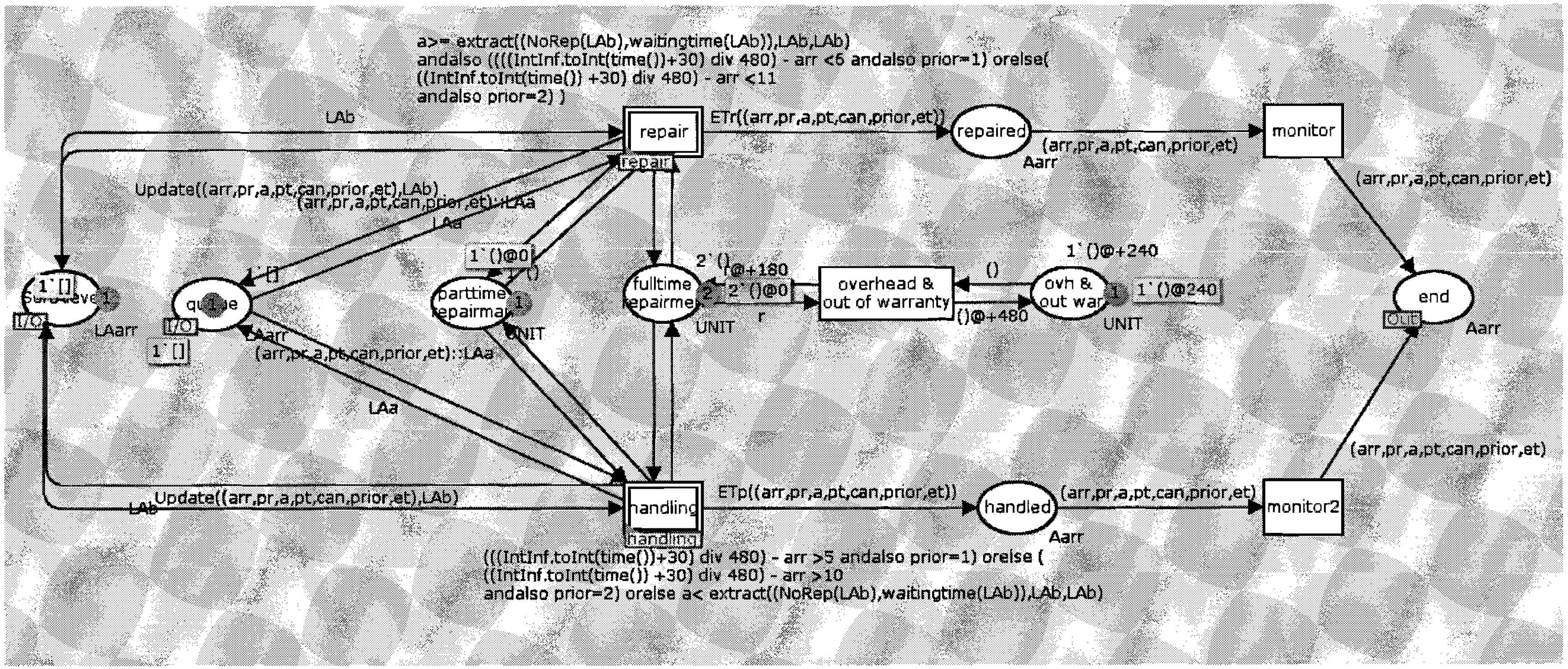
Appendix 12.3: Design 3

12.3.1: The total model (superpage)



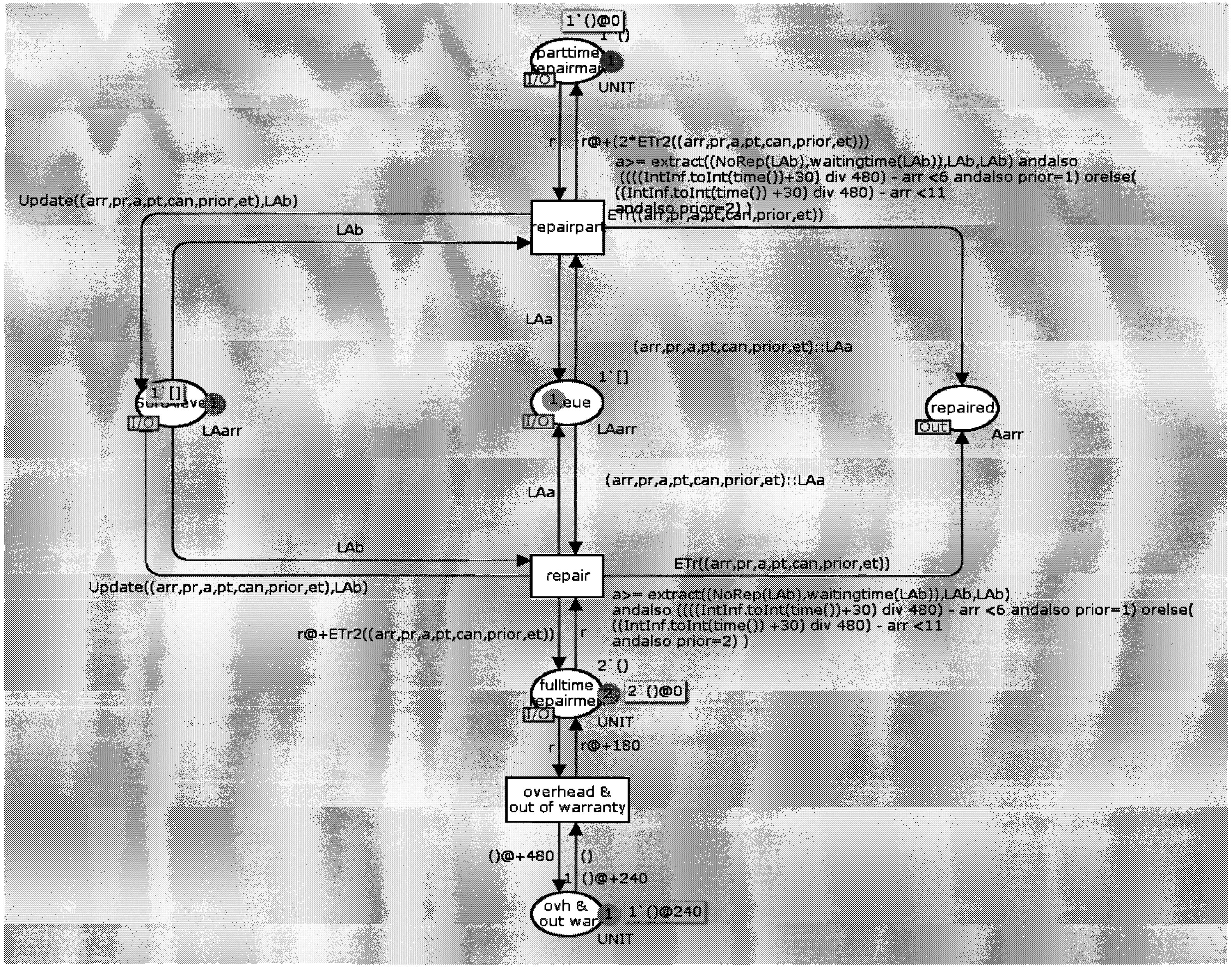


12.3.2: Select (subpage)

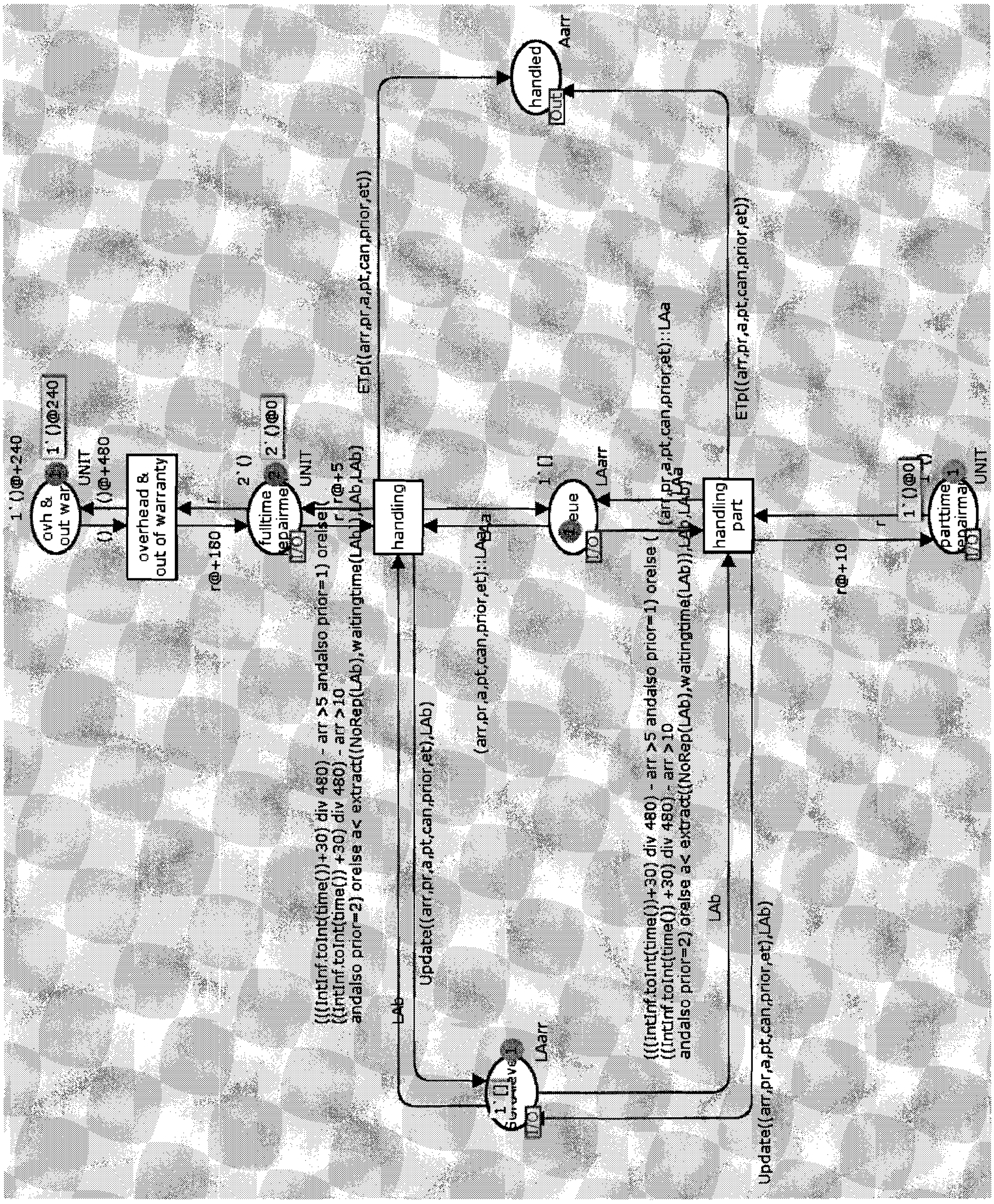


a>= extract((NoRep(LAb),waitingtime(LAb)),LAb,LAb)
andalso ((((IntInf.toInt(time())+30) div 480) - arr <6 andalso prior=1) orelse(
((IntInf.toInt(time()) +30) div 480) - arr <11
andalso prior=2))
repair
ETr((arr,pr,a,pt,can,prior,et))
repaired
Aarr
(arr,pr,a,pt,can,prior,et)
monitor
(arr,pr,a,pt,can,prior,et)
LAb
Update((arr,pr,a,pt,can,prior,et),LAb)
(arr,pr,a,pt,can,prior,et)::LAa
LAa
1`()@0
1`()
1`[]
I/O
LAarr
queue
1`[]
parttime repairman
UNIT
fulltime repairmen
2`()
r@+180
2`()@0
r
UNIT
overhead & out of warranty
()
()@+480
1`()@+240
ovh & out war
1`()@240
UNIT
end
Out
Aarr
(arr,pr,a,pt,can,prior,et)::LAa
LAa
(arr,pr,a,pt,can,prior,et)
Update((arr,pr,a,pt,can,prior,et),LAb)
LAb
handling
ETp((arr,pr,a,pt,can,prior,et))
handled
(arr,pr,a,pt,can,prior,et)
monitor2
Aarr
(((IntInf.toInt(time())+30) div 480) - arr >5 andalso prior=1) orelse (
((IntInf.toInt(time()) +30) div 480) - arr >10
andalso prior=2) orelse a< extract((NoRep(LAb),waitingtime(LAb)),LAb,LAb)

12.3.4: Repair (subpage)



12.3.5: Handling (subpage)



Appendix 12.4: Declarations

12.4.1: Declarations 1

```
▼Declarations
  ▶Standard declarations
  ▼colset arrtime = INT timed;
  ▼colset price = INT;
  ▼colset A = INT timed;
  ▼colset processingtime = INT;
  ▼colset cannibalization = INT;
  ▼colset priority = INT;
  ▼colset endtime = INT;
  ▼colset day=INT;
  ▼var day:day;
  ▼colset dayvalue = INT;
  ▼colset daydayvalue = product day *dayvalue;
  ▼colset wvar= product INT * INT;
  ▼var dt: INT;
  ▼colset Aarr = product arrtime * price *
    A *processingtime * cannibalization *
    priority * endtime timed;
  ▼colset LAarr = list Aarr;
  ▼var arr: arrtime;
  ▼var pr: price;
  ▼var a: A;
  ▼var pt: processingtime;
  ▼var dv: dayvalue;
  ▼var can: cannibalization;
  ▼var fw: INT;
  ▼var wk: INT;
  ▼var prior: INT ;
  ▼var et: endtime;
  ▼var LAa :LAarr;
  ▼var LAb: LAarr;
  ▼fun AT(a) =(IntInf.toInt(time())) div 480;
  ▼fun renewday(a,b) = if a=1 then (2,125) else if a=2 then (3,85)
    else if a=3 then (4,125) else if a=4 then (5,85) else (1,85);
  ▼fun Price(a,b,c,d,e,f,g) = if discrete(0,19) = 19 then (a,round(normal(1000.0,250.0)),c,discrete(15,25),e,f,g)
    else if discrete(0,19)>14 then  (a,
    round(normal(175.0,25.0)),c,discrete(25,45),e,f,g) else if discrete(0,19) >8 then (a,
    round(normal(75.0,8.33)),c,discrete(20,40),e,f,g) else if discrete(0,19)>2
    then (a,round(normal(37.5,4.17)),c,discrete(20,40),e,f,g) else (a,round(normal(12.5,4.17)),c,discrete(15,25),e,f,g);
  ▼fun renew4(a,b) = if a=1 then (2,109)
    else if a=2 then (3,100)
    else if a=2 then (4, 92)
    else if a=4 then (5,106)
    else if a=5 then (6,96)
    else if a=6 then (7,100)
    else if a=7 then (8,111)
    else if a=8 then (9,95)
    else if a=9then (10, 90)
    else if a=10 then (11, 86)
    else if a=11 then (12,89)
    else if a=12 then (13,115) else (1,111);
  ▼fun cannibal(a)= if discrete (0,99)<16 then 1 else 0;
  ▼fun priority(a) = if discrete(0,9)<3 then 2 else 1;
  ▼var rl: INT;
  ▼fun A(a,b,c,d,e,f,g) =(a,b,b*10 div d,d, e,f,g);
```

12.4.2: Declarations 2

```
▼var r: UNIT;
▼fun Sort((a,b,c,d,e,f,g),[]) = [(a,b,c,d,e,f,g)] |
  Sort((a,b,c,d,e,f,g),(h,i,j,k,l,m,n)::t) = if f=m andalso a<h
  then (a,b,c,d,e,f,g)::((h,i,j,k,l,m,n)::t)
  else if f<m andalso a - h <=1 then (a,b,c,d,e,f,g)::((h,i,j,k,l,m,n)::t) else
  (h,i,j,k,l,m,n)::Sort((a,b,c,d,e,f,g),t);
▼fun ET(a,b,c,d,e,f,g) = if e=0 then (a,b,c,d,e,f,((IntInf.toInt(time())
   + round(normal(real(d),5.0)))) div 480) else (a,b,c,d,e,f,((IntInf.toInt(time())
  + round(normal(real(d),5.0)) + 15) )div 480) ;
▼fun Sortfive((a,b,c,d,e,f,g),[]) = [(a,b,c,d,e,f,g)] |
  Sortfive((a,b,c,d,e,f,g),(h,i,j,k,l,m,n)::t) = if f=m andalso a<h
  then (a,b,c,d,e,f,g)::((h,i,j,k,l,m,n)::t)
  else if f<m andalso a - h <=5 then (a,b,c,d,e,f,g)::((h,i,j,k,l,m,n)::t) else
  (h,i,j,k,l,m,n)::Sort((a,b,c,d,e,f,g),t);
▼fun ET2(a,b,c,d,e,f,g) = if e=0 then
  round(normal(real(d),5.0)) else
   round(normal(real(d),5.0)) + 15 ;
▼fun Abep(a,b) = if a=0 then 35 else if b - 190 > 60 then a+6 else if b-190>50
  then a+5 else if b-190>40 then a+4 else if b-190>30 then a+3
  else if b-190>20 then a+2 else if b-190>10 then a+1 else if 190-b>60 then a-6
  else if 190-b>50 then a-5 else if 190-b>40 then a-4 else if 190-b> 30 then a-3
  else if 190-b>20 then a-2 else if b-190<10 andalso 190-b<10 then a else a-1;
▶fun RetBep
```

Appendix 13

The graphs displayed in this appendix display the results for simulated scenarios. The terminology used was introduced in chapter 12 and describes the level of the sales prices and repair times compared to the present, normal, situation. The results within the different redesigns are divided in four large scenario combinations being:

- normal value distribution and normal processing times
- high value distribution and normal processing times
- low value distribution and normal processing times
- normal value distribution and high processing times

The appendix displays two types of graphs. The first type displays the total sales value of the products repaired on time per WIP level used for control. The second displays the total number of products repaired on time per WIP level used for control. Both type of graphs cover the full year of observations.

Appendix 13.1: Results for Design 1

13.1.1.: Total value per WIP level for Design 1

13.1.1.1: Normal value distribution, normal processing times

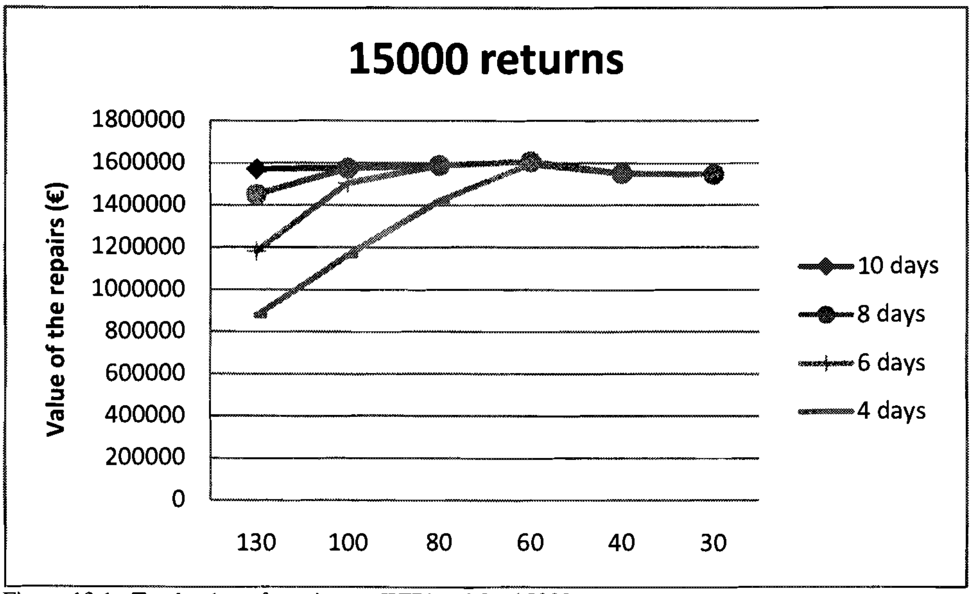


Figure 13.1.: Total value of repairs per WIPlevel for 15000 returns

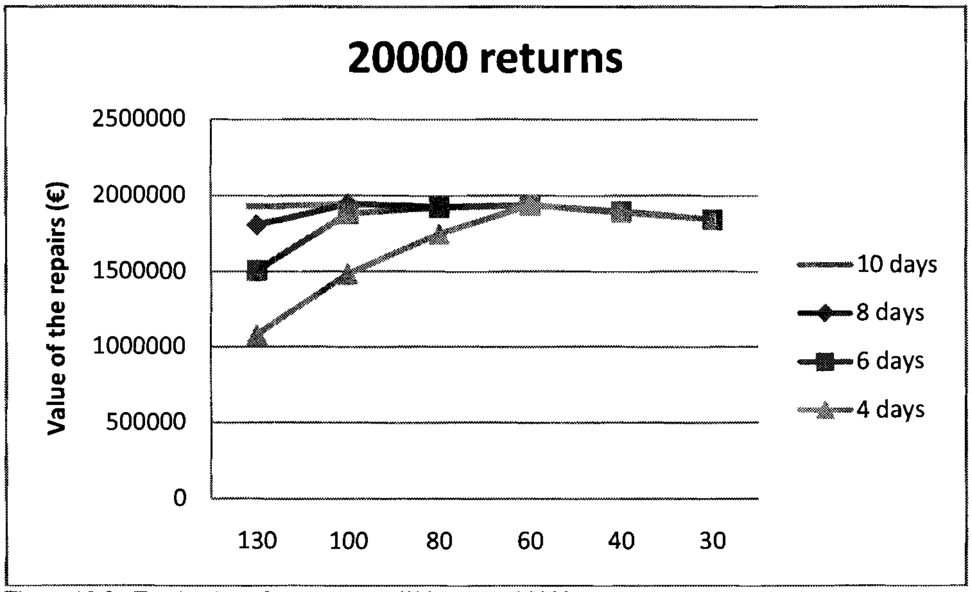


Figure 13.2.: Total value of repairs per WIPlevel for 20000 returns

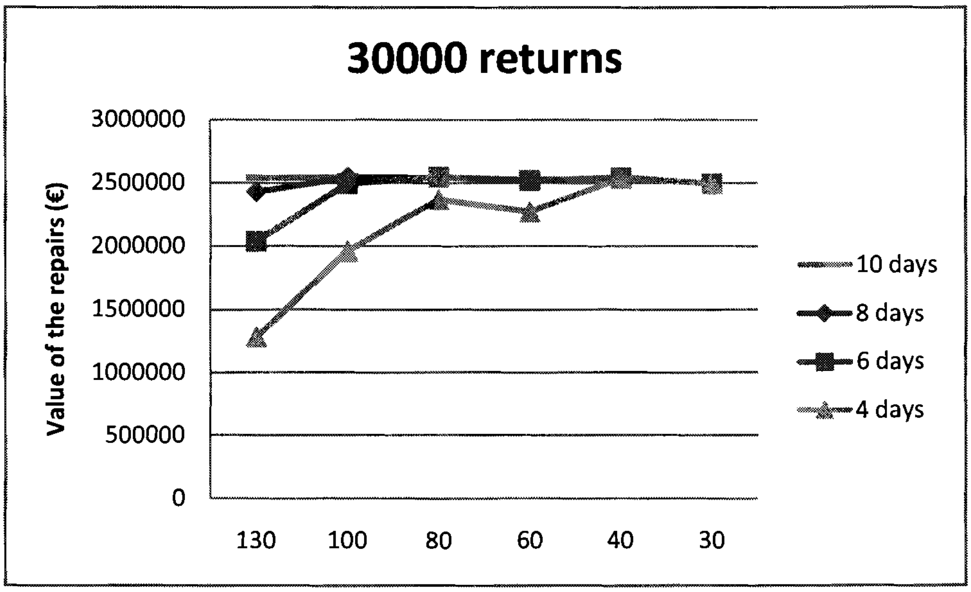


Figure 13.3.: Total value of repairs per WIPlevel for 30000 returns

13.1.1.2: High value distribution, normal processing times

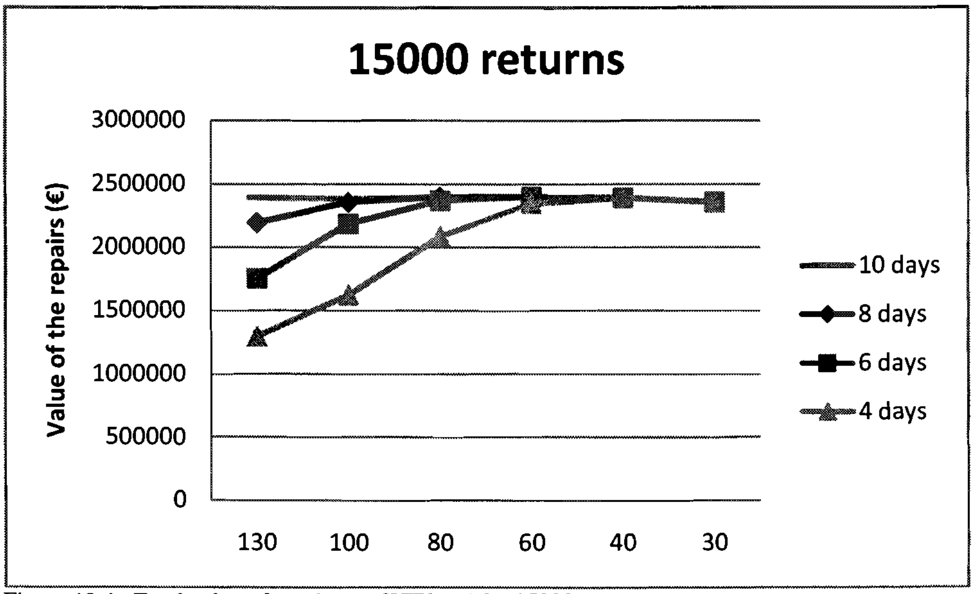


Figure 13.4.: Total value of repairs per WIPlevel for 15000 returns

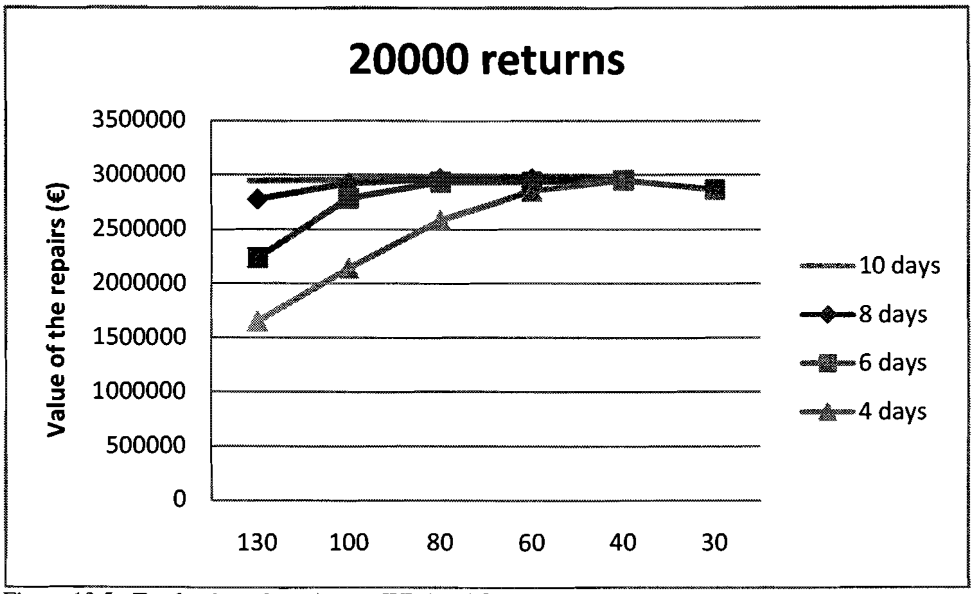


Figure 13.5.: Total value of repairs per WIPlevel for 20000 returns

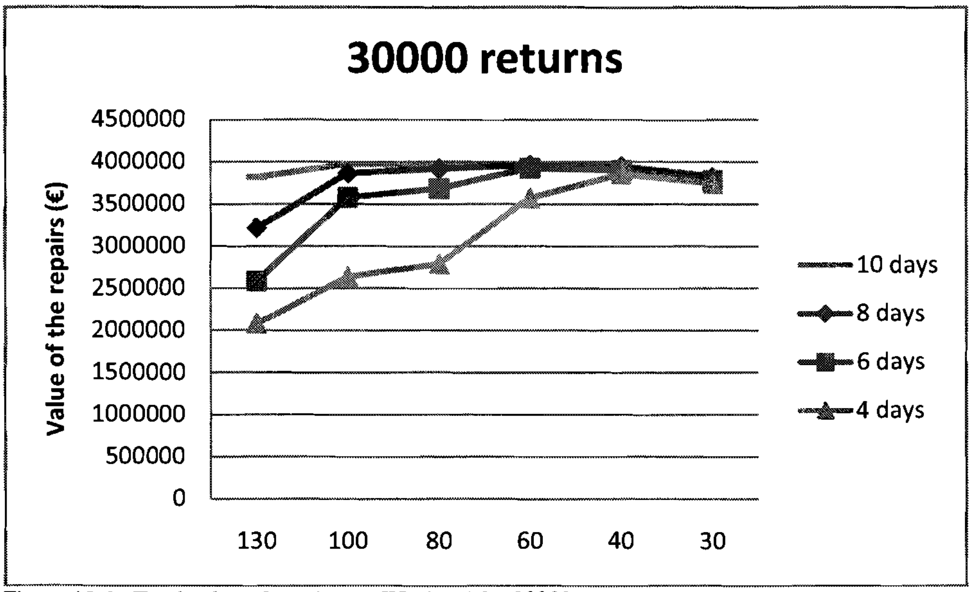


Figure 13.6.: Total value of repairs per WIPlevel for 30000 returns

13.1.1.3: Low value distribution, normal processing times

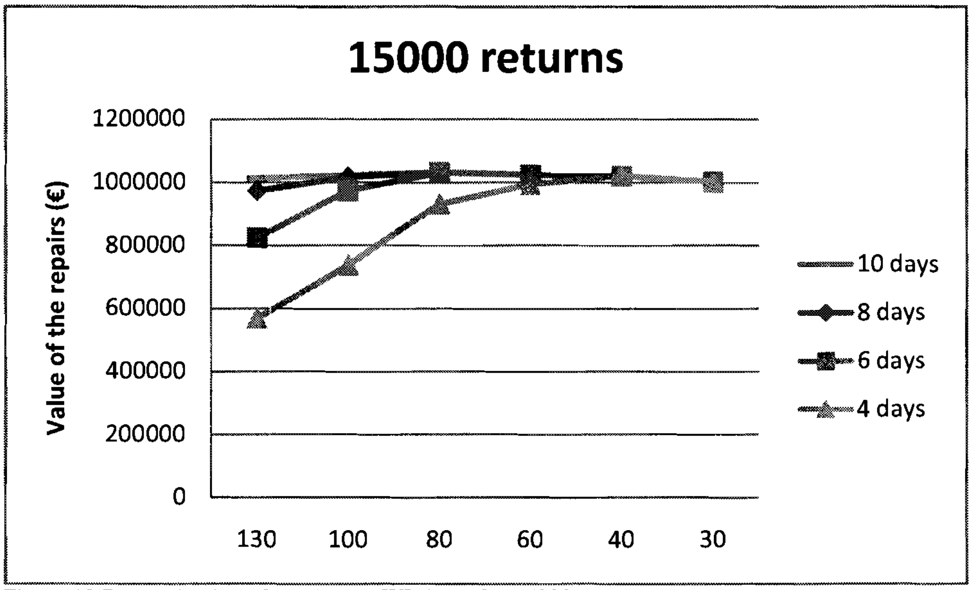


Figure 13.7.: Total value of repairs per WIPlevel for 15000 returns

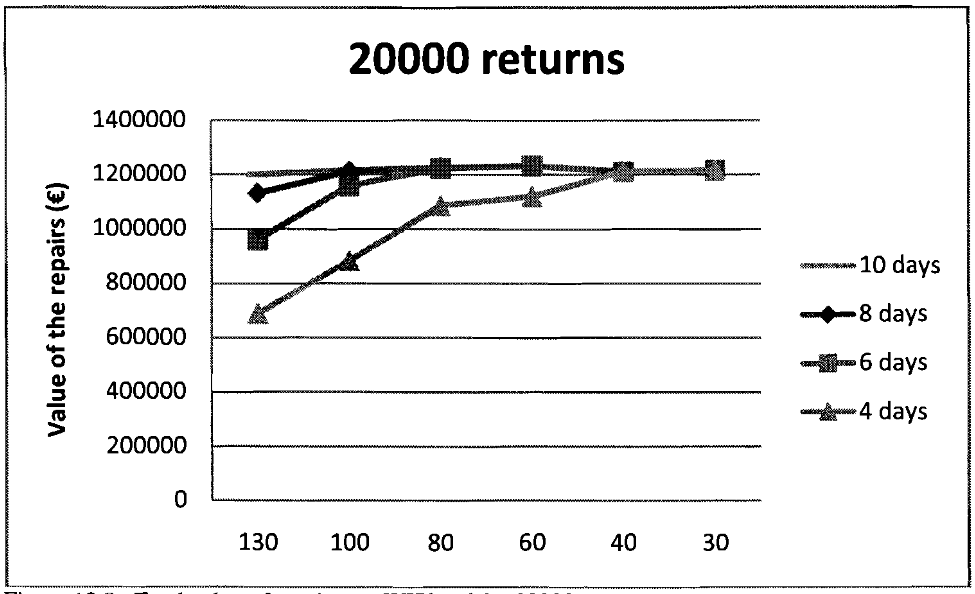


Figure 13.8.: Total value of repairs per WIPlevel for 20000 returns

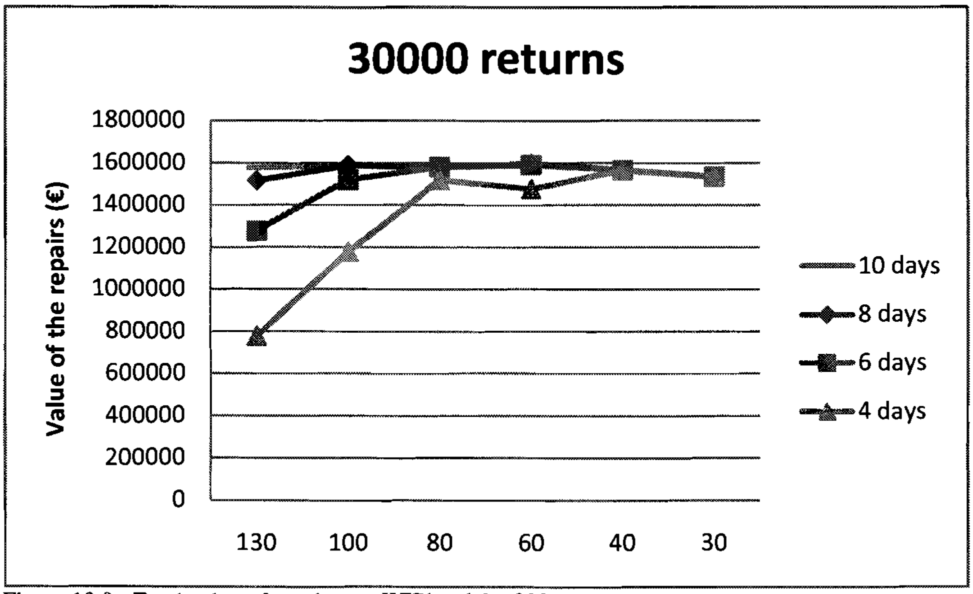


Figure 13.9.: Total value of repairs per WIPlevel for 30000 returns

13.1.1.4: Normal value distribution, low processing times

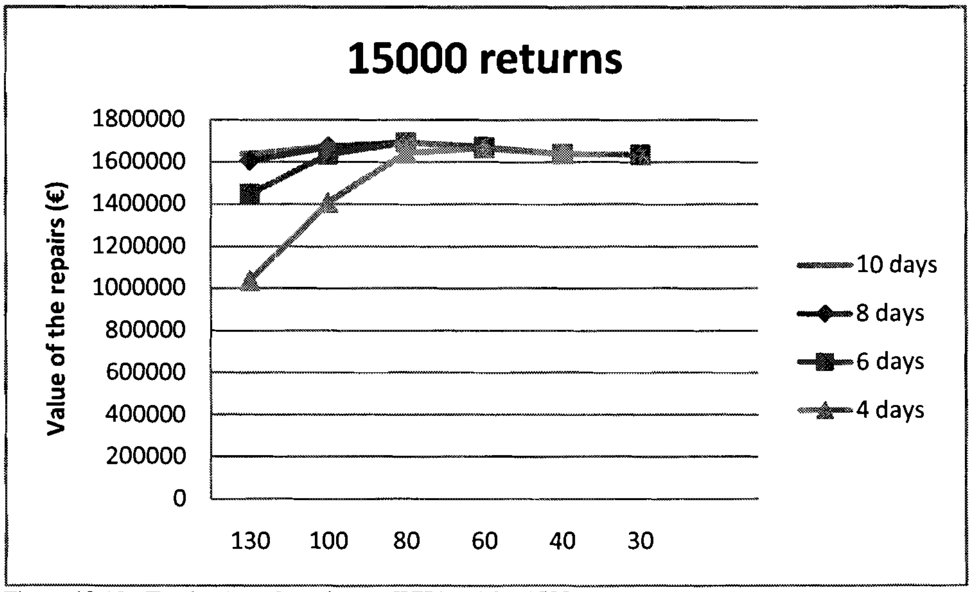


Figure 13.10.: Total value of repairs per WIPlevel for 15000 returns

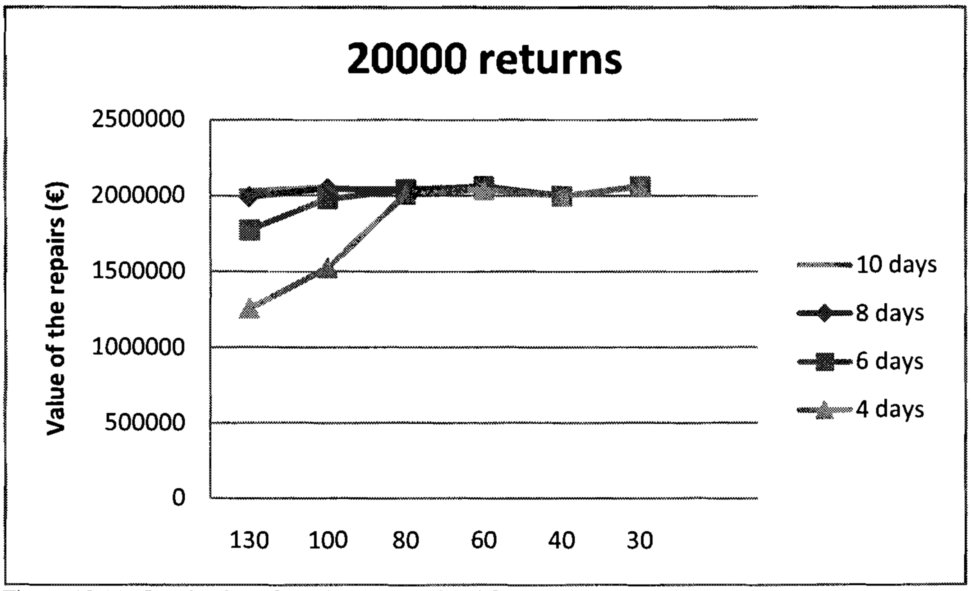


Figure 13.11.: Total value of repairs per WIPlevel for 20000 returns

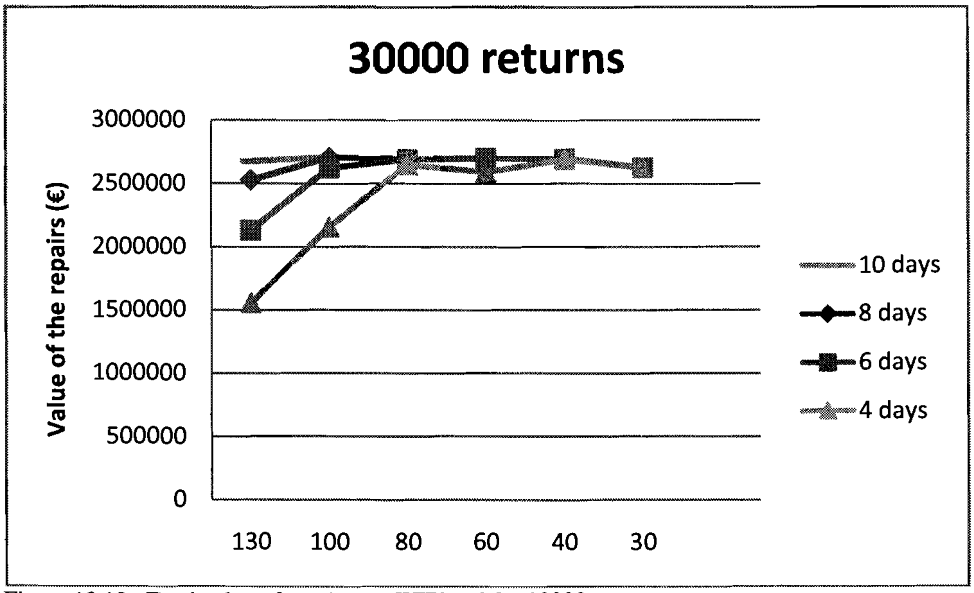


Figure 13.12.: Total value of repairs per WIPlevel for 30000 returns

13.1.2: Number of repairs per WIPlevel

13.1.2.1.: Normal value distribution, normal processing times

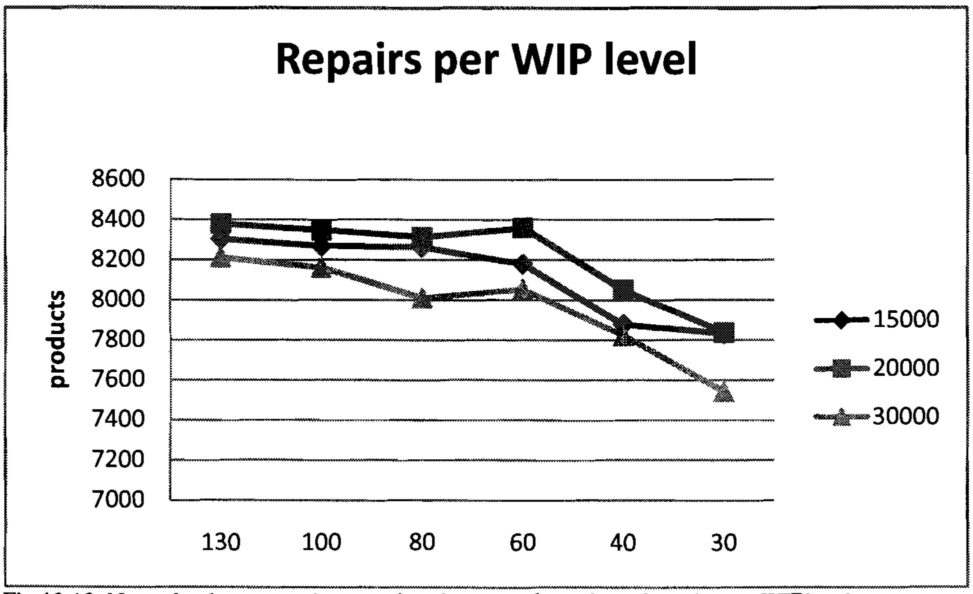


Fig 13.13. Normal value, normal processing times: total number of repairs per WIPlevel,

13.1.2.2: High value distribution, normal processing times

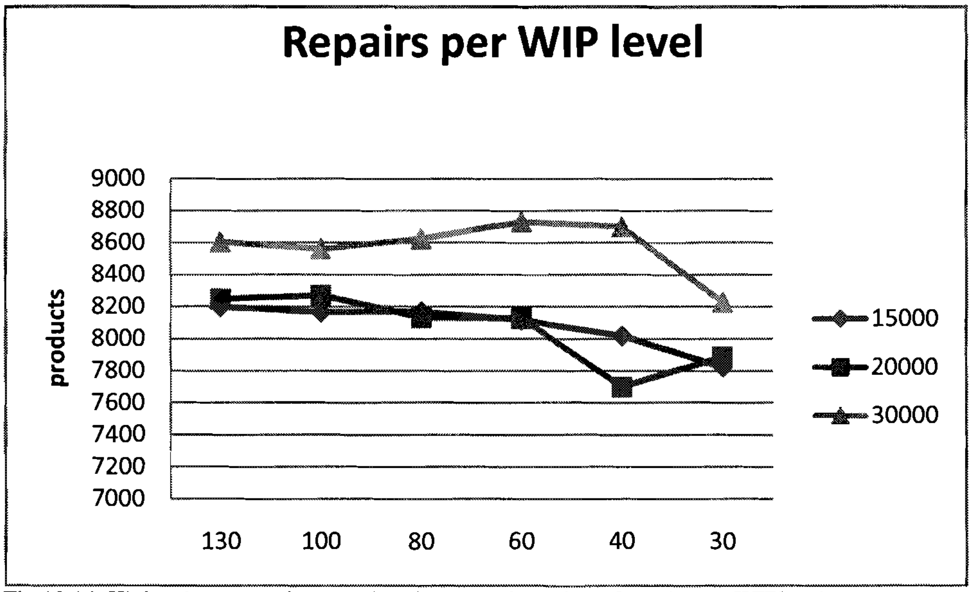


Fig 13.14. High value, normal processing times: total number of repairs per WIPlevel,

13.1.2.3: Low value distribution, normal processing times

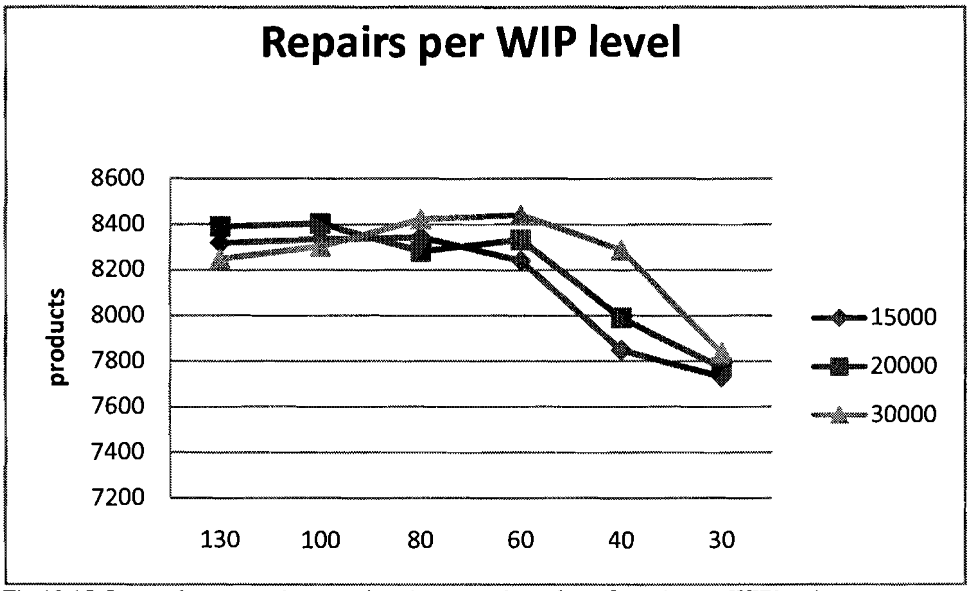


Fig 13.15. Low value, normal processing times: total number of repairs per WIPlevel,

13.1.2.4: Normal value distribution, low processing times

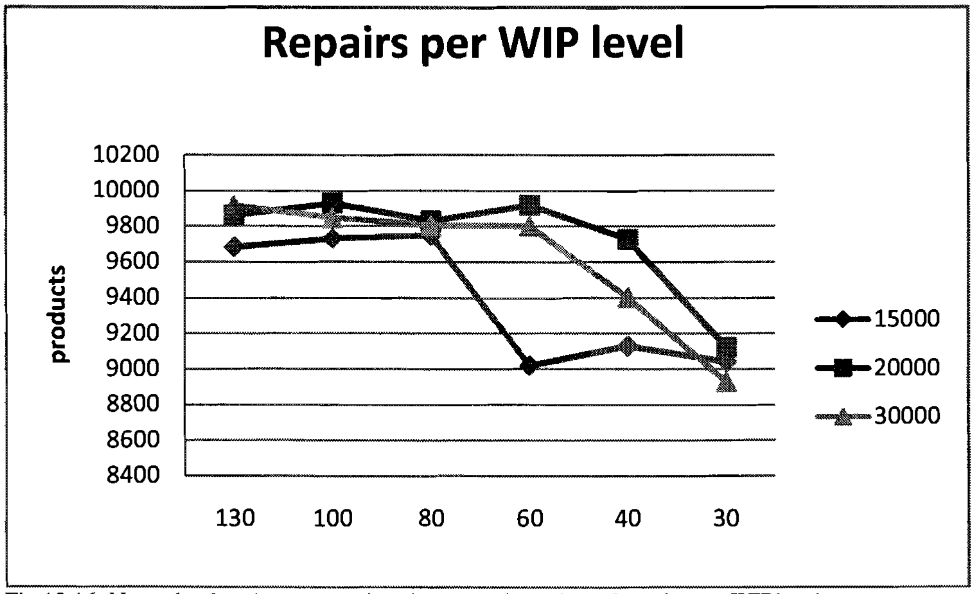


Fig 13.16. Normal value, low processing times: total number of repairs per WIPlevel,

13.1.3.: Priority rule effects

The tables display the effect of the priority rule, again for the combination of circumstances as defined in chapter 12. For each combination, the first table displays the percentage of late products for each scenario. The second displays the percentage of products finished within the maximum throughput time for priority products. The second two tables display the same information in case 70% are priority products.

13.1.3.1.: Normal value distribution, normal processing times

		20000			30000			15000		
		FCFS	1 day	5 days	FCFS	1 day	5 days	FCFS	1 day	5 days
max days	WIPlevel	% products l	% products l	% products l	% products l	% products l	% products l	% products l	% products l	% products l
10	130	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.1%	0.1%	0.0%
	100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	130	6.3%	5.3%	4.2%	4.4%	3.8%	3.0%	7.7%	6.9%	5.7%
	100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	130	21.7%	20.3%	18.2%	20.0%	18.5%	16.5%	24.4%	23.3%	21.3%
	100	3.4%	2.4%	1.1%	2.0%	1.2%	0.5%	4.3%	3.4%	2.1%
	80	0.4%	0.2%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	130	44.1%	44.0%	42.5%	49.9%	48.8%	47.9%	48.9%	43.7%	43.6%
	100	24.7%	21.3%	17.6%	24.8%	20.3%	16.8%	24.5%	23.4%	20.6%
	80	9.9%	8.4%	5.4%	7.0%	4.6%	2.3%	10.6%	7.8%	5.2%
	60	0.0%	0.0%	0.2%	4.9%	0.5%	0.0%	0.1%	0.0%	0.0%
	40	0.3%	0.2%	0.1%	0.2%	0.1%	0.0%	0.0%	0.0%	3.5%
	30	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 13.1: Percentage of products late per WIP level, given priority and maximal throughput time, 90%

		20000			30000			15000		
		FCFS	1day	5 days	FCFS	1day	5 days	FCFS	1day	5 days
max days	WIPlevel	% products v	% products v	% products v	% products v	% products v	% products v	% products v	% products v	% products v
10	130	100.0%	99.8%	97.2%	99.9%	99.8%	97.4%	99.9%	99.8%	96.8%
	100	100.0%	100.0%	99.6%	100.0%	100.0%	99.8%	100.0%	100.0%	99.5%
	80	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	60	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
8	130	93.0%	92.9%	89.9%	95.1%	94.5%	89.8%	91.5%	91.0%	88.7%
	100	100.0%	100.0%	94.7%	100.0%	100.0%	94.7%	100.0%	99.8%	94.5%
	80	100.0%	100.0%	96.8%	100.0%	100.0%	97.1%	100.0%	100.0%	96.1%
	60	100.0%	100.0%	99.1%	100.0%	100.0%	96.8%	100.0%	100.0%	99.1%
	40	100.0%	100.0%	97.2%	100.0%	100.0%	99.6%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
6	130	75.9%	75.4%	75.2%	77.7%	76.7%	77.0%	72.9%	72.4%	71.4%
	100	96.2%	95.9%	91.0%	97.8%	97.2%	91.7%	95.3%	94.7%	89.9%
	80	99.6%	99.4%	92.7%	100.0%	99.9%	92.5%	99.9%	99.6%	91.9%
	60	100.0%	100.0%	93.9%	99.9%	99.6%	92.3%	100.0%	100.0%	93.5%
	40	100.0%	100.0%	99.8%	100.0%	100.0%	94.5%	100.0%	100.0%	96.5%
	30	100.0%	100.0%	99.0%	100.0%	100.0%	97.8%	100.0%	100.0%	98.9%
4	130	51.3%	50.1%	54.6%	44.7%	44.0%	49.1%	55.6%	50.7%	53.2%
	100	72.5%	73.0%	76.7%	74.2%	74.2%	77.9%	71.1%	70.8%	73.9%
	80	89.1%	87.7%	87.9%	92.3%	91.7%	90.4%	88.2%	87.9%	87.5%
	60	98.5%	97.4%	93.1%	89.1%	88.4%	88.5%	98.8%	97.5%	92.5%
	40	99.7%	99.4%	96.3%	99.8%	99.0%	93.5%	100.0%	99.9%	95.3%
	30	99.9%	100.0%	98.2%	100.0%	100.0%	96.9%	100.0%	100.0%	98.0%

Table 13.2: Percentage of products within x days per WIP level, given priority and maximal throughput time, 90%

max days	WIPlevel	15000 1 day	5 days	20000 1 day	5 days	30000 1 day	5 days
		% products late		% products late		% products late	
10	130	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	130	0.9%	0.1%	0.6%	0.0%	2.1%	0.7%
	100	1.5%	0.2%	0.0%	0.0%	0.0%	0.0%
	80	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	130	10.6%	5.2%	7.2%	3.3%	10.0%	6.1%
	100	8.5%	4.7%	1.5%	0.0%	2.3%	0.1%
	80	2.5%	1.1%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	130	30.3%	26.9%	29.6%	20.9%	31.8%	25.8%
	100	30.1%	23.9%	16.6%	7.1%	18.1%	10.3%
	80	28.2%	8.3%	3.6%	1.1%	2.5%	0.2%
	60	0.4%	0.0%	3.1%	0.2%	3.6%	0.7%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 13.3: Percentage of products late per WIP level, given priority and maximal throughput time, 70%

Nr of days r	WIP level	15000 1 day	 5 days	20000 1 day	 5 days	30000 1 day	 5 days
		% products within x days		% products within x days		% products within x days	
10	130	97.7%	100.0%	98.2%	100.0%	97.2%	99.9%
	100	97.6%	100.0%	99.9%	100.0%	99.9%	100.0%
	80	99.5%	100.0%	100.0%	100.0%	100.0%	100.0%
	60	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
8	130	84.8%	96.5%	84.5%	97.3%	82.8%	94.8%
	100	84.5%	95.3%	90.2%	99.8%	89.1%	99.7%
	80	90.3%	99.1%	97.7%	100.0%	98.4%	100.0%
	60	99.7%	100.0%	97.8%	100.0%	97.5%	99.9%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
6	130	74.6%	81.1%	72.0%	82.9%	71.2%	78.9%
	100	73.9%	78.3%	76.2%	93.4%	78.8%	92.1%
	80	78.7%	92.3%	84.0%	99.2%	83.6%	99.6%
	60	87.5%	100.0%	81.9%	99.4%	83.8%	99.0%
	40	99.5%	100.0%	99.4%	100.0%	95.3%	100.0%
	30	97.6%	100.0%	95.6%	100.0%	99.5%	100.0%
4	130	61.1%	53.6%	60.7%	48.9%	58.5%	47.9%
	100	59.1%	51.7%	70.2%	65.5%	71.4%	65.2%
	80	72.2%	67.1%	78.9%	86.8%	80.2%	87.9%
	60	82.0%	93.7%	77.5%	88.7%	79.2%	86.6%
	40	96.2%	99.9%	96.8%	100.0%	88.6%	99.0%
	30	92.1%	99.6%	90.1%	99.1%	96.3%	100.0%

Table 13.4: Percentage of products within x days per WIP level, given priority and maximal throughput time, 70%

13.1.3.2: High value distribution, normal processing times

		20000			15000			30000		
		FCFS	1 day	5 days	FCFS	1 day	5 days	FCFS	1 day	5 days
max days	WIPlevel	% products	% products	% products	% products	% products	% products	% products	% products	% products
10	130	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	3.1%	2.5%
	100	0.1%	0.1%	0.0%	0.0%	0.0%	0.1%	0.3%	0.3%	0.2%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.2%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	130	5.5%	4.9%	4.3%	8.2%	6.9%	5.9%	19.0%	17.4%	15.1%
	100	1.0%	0.8%	0.8%	1.1%	0.8%	0.3%	2.8%	2.5%	2.2%
	80	0.7%	0.6%	0.5%	0.0%	0.1%	0.0%	1.2%	1.0%	0.8%
	60	0.7%	0.6%	0.6%	0.0%	0.0%	0.0%	0.4%	0.4%	0.3%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.2%	0.1%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.3%	0.3%
6	130	23.9%	22.3%	19.4%	26.3%	24.9%	23.6%	35.7%	34.7%	34.6%
	100	5.4%	4.4%	3.3%	8.0%	6.8%	5.0%	9.9%	8.8%	7.3%
	80	1.5%	1.4%	1.4%	1.1%	0.9%	0.6%	7.0%	6.1%	4.7%
	60	1.4%	1.4%	1.3%	0.0%	0.0%	0.0%	1.1%	1.0%	1.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	1.1%	1.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	1.2%	1.1%
4	130	44.5%	43.4%	44.1%	45.8%	45.0%	45.5%	48.8%	49.0%	49.6%
	100	28.4%	25.3%	21.5%	32.1%	29.0%	26.9%	33.4%	32.1%	29.7%
	80	13.2%	10.0%	7.8%	12.9%	10.7%	8.4%	30.3%	28.0%	25.5%
	60	4.1%	1.4%	2.5%	2.1%	0.0%	0.8%	10.0%	1.0%	4.6%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.0%	1.9%	1.9%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.9%	2.0%	2.0%

Table 13.5: Percentage of products late per WIP level, given priority and maximal throughput time, 90%

		20000			15000			30000		
		FCFS	1 day	5 days	FCFS	1 day	5 days	FCFS	1 day	5 days
max days	WIPlevel	% products	% products	% products	% products	% products	% products	% products	% products	% products
10	130	99.8%	99.8%	96.9%	100.0%	99.8%	96.6%	96.2%	96.0%	93.2%
	100	99.9%	99.9%	99.4%	100.0%	100.0%	99.0%	99.6%	99.6%	98.6%
	80	100.0%	100.0%	99.8%	100.0%	100.0%	99.9%	100.0%	100.0%	99.1%
	60	99.8%	99.8%	99.8%	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%	99.8%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%
8	130	93.9%	93.2%	89.9%	90.9%	90.7%	88.8%	79.0%	79.2%	80.6%
	100	98.9%	98.9%	94.1%	98.8%	98.6%	94.1%	96.9%	96.8%	92.4%
	80	99.3%	99.3%	95.8%	100.0%	100.0%	96.3%	98.7%	98.5%	94.0%
	60	99.2%	99.2%	97.9%	100.0%	100.0%	98.7%	99.5%	99.5%	96.5%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.6%	99.7%	99.5%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.5%	99.5%	99.4%
6	130	73.5%	73.3%	75.7%	70.8%	70.8%	71.7%	60.7%	60.9%	62.2%
	100	94.1%	93.4%	89.5%	91.0%	90.6%	88.0%	89.0%	88.4%	86.6%
	80	98.3%	97.9%	91.2%	98.7%	98.4%	92.1%	92.2%	91.5%	88.9%
	60	98.4%	98.4%	92.4%	100.0%	100.0%	93.8%	98.8%	98.6%	92.4%
	40	100.0%	100.0%	99.7%	100.0%	100.0%	97.1%	98.7%	98.7%	94.3%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	98.9%	98.6%	98.6%	97.7%
4	130	50.9%	51.0%	53.2%	49.7%	49.9%	51.8%	47.0%	47.0%	48.4%
	100	69.6%	69.2%	73.7%	64.7%	65.3%	68.8%	62.4%	62.7%	67.0%
	80	85.3%	85.7%	85.6%	85.6%	84.7%	85.2%	66.5%	66.7%	70.5%
	60	95.5%	94.7%	90.8%	97.6%	96.6%	92.4%	88.8%	88.6%	89.0%
	40	100.0%	100.0%	98.8%	100.0%	99.8%	96.2%	97.8%	97.4%	92.6%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	98.1%	97.9%	97.8%	96.2%

Table 13.6: Percentage of products within x days per WIP level, given priority and maximal throughput time, 90%

		15000		20000		30000	
		1day	5 days	1day	5 days	1day	5 days
Nr of days r	WIP level	% products late		% products late		% products late	
10	130	0.0%	0.0%	0.1%	0.0%	0.4%	0.0%
	100	0.0%	0.0%	0.0%	0.0%	1.6%	1.2%
	80	0.0%	0.0%	0.0%	0.0%	0.5%	0.1%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	130	1.6%	0.5%	4.3%	3.1%	7.4%	4.5%
	100	0.1%	0.0%	0.5%	0.0%	3.3%	3.4%
	80	0.0%	0.0%	0.0%	0.0%	1.8%	1.9%
	60	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	130	10.2%	5.6%	15.4%	11.6%	22.4%	17.4%
	100	2.4%	1.1%	7.3%	3.3%	4.9%	4.2%
	80	0.0%	0.0%	0.0%	0.1%	2.9%	2.9%
	60	0.0%	0.0%	0.0%	0.0%	0.9%	0.7%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	130	29.5%	26.5%	33.4%	30.7%	37.0%	39.1%
	100	17.9%	11.3%	24.7%	20.1%	15.3%	9.2%
	80	8.4%	2.6%	4.6%	1.0%	5.9%	4.3%
	60	0.4%	0.0%	0.8%	0.0%	5.2%	0.2%
	40	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 13.7: Percentage of products late per WIP level, given priority and maximal throughput time, 70%

Nr of days r	WIPlevel	15000 1 day % products within x days	 5 days	20000 1 day % products within x days	 5 days	30000 1 day % products within x days	 5 days
10	130	100.0%	97.5%	99.2%	95.2%	98.3%	92.6%
	100	100.0%	99.5%	100.0%	98.2%	97.4%	97.8%
	80	100.0%	100.0%	100.0%	100.0%	99.0%	98.8%
	60	100.0%	100.0%	100.0%	100.0%	100.0%	99.6%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
8	130	95.4%	84.8%	90.3%	83.7%	84.8%	83.2%
	100	99.3%	90.5%	97.2%	86.4%	95.8%	92.2%
	80	100.0%	94.8%	100.0%	97.2%	97.3%	97.4%
	60	100.0%	99.5%	100.0%	99.3%	99.5%	97.1%
	40	100.0%	99.7%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	99.9%	100.0%	100.0%	100.0%	100.0%
6	130	79.6%	77.2%	73.3%	66.3%	65.1%	61.4%
	100	91.9%	80.4%	83.9%	78.1%	91.3%	81.2%
	80	97.7%	82.6%	99.1%	84.6%	95.8%	86.1%
	60	99.9%	89.6%	99.8%	86.4%	97.8%	85.2%
	40	100.0%	89.5%	100.0%	99.2%	100.0%	96.6%
	30	100.0%	98.7%	100.0%	95.8%	100.0%	99.8%
4	130	53.2%	65.4%	49.8%	59.6%	49.9%	56.3%
	100	67.1%	78.5%	58.8%	76.2%	71.7%	78.5%
	80	91.6%	79.7%	85.2%	80.8%	87.0%	81.5%
	60	95.6%	84.6%	92.3%	81.7%	86.0%	80.8%
	40	94.8%	85.2%	99.9%	96.5%	99.3%	90.4%
	30	99.6%	96.2%	98.9%	89.4%	100.0%	98.7%

Table 13.8: Percentage of products within x days per WIP level, given priority and maximal throughput time, 70%

13.1.3.3: Low value distribution, normal processing times

		20000			15000			30000		
		FCFS	1 day	5 days	FCFS	1 day	5 days	FCFS	1 day	5 days
max days	WIPlevel	% products	% products	% products	% products	% products	% products	% products	% products	% products
10	130	0.3%	0.1%	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	0.0%
	100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	130	6.0%	5.0%	4.3%	3.8%	3.2%	2.2%	4.2%	3.7%	3.1%
	100	0.4%	0.3%	0.3%	0.5%	0.4%	0.3%	0.2%	0.1%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	130	18.4%	15.9%	15.0%	18.5%	16.3%	14.6%	19.3%	17.2%	15.2%
	100	4.8%	3.8%	2.7%	4.8%	3.5%	2.5%	4.4%	3.7%	2.4%
	80	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.2%	0.1%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	130	43.1%	40.8%	40.7%	44.3%	41.8%	41.4%	51.4%	56.8%	48.2%
	100	27.5%	24.9%	21.3%	28.0%	24.7%	21.8%	26.2%	22.8%	18.3%
	80	11.5%	8.7%	4.9%	9.8%	7.7%	4.3%	4.0%	2.4%	1.1%
	60	9.0%	0.0%	3.5%	2.9%	0.0%	0.9%	7.6%	0.2%	4.1%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.5%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 13.9: Percentage of products late per WIP level, given priority and maximal throughput time, 90%

		20000			15000			30000		
		FCFS	1 day	5 days	FCFS	1 day	S days	FCFS	1 day	5 days
max days	WIPlevel	% products	% products	% products	% products	% products	% product	% products	% products	% products
10	130	99.7%	99.7%	97.4%	100.0%	100.0%	97.4%	99.8%	99.8%	97.3%
	100	100.0%	100.0%	99.4%	100.0%	100.0%	99.5%	100.0%	100.0%	99.4%
	80	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	60	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
8	130	93.3%	93.4%	89.6%	95.8%	95.4%	91.1%	95.4%	94.8%	89.3%
	100	99.6%	99.4%	94.2%	99.5%	99.4%	94.3%	99.8%	99.6%	94.8%
	80	100.0%	100.0%	96.1%	100.0%	100.0%	96.5%	100.0%	100.0%	97.8%
	60	100.0%	100.0%	96.6%	100.0%	100.0%	98.4%	100.0%	100.0%	97.1%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
6	130	79.6%	80.2%	78.9%	79.5%	79.5%	79.1%	78.6%	78.3%	78.0%
	100	94.7%	94.1%	90.1%	94.7%	94.3%	89.9%	95.1%	94.4%	89.7%
	80	99.8%	99.5%	92.7%	99.9%	99.7%	92.4%	100.0%	99.9%	91.9%
	60	100.0%	99.7%	92.4%	100.0%	100.0%	93.3%	99.6%	99.4%	92.0%
	40	100.0%	100.0%	98.3%	100.0%	100.0%	97.5%	100.0%	100.0%	95.5%
	30	100.0%	100.0%	96.4%	100.0%	100.0%	98.9%	100.0%	100.0%	99.0%
4	130	52.4%	53.1%	56.3%	50.9%	51.7%	55.4%	43.3%	50.8%	48.7%
	100	69.6%	69.5%	74.0%	69.4%	69.6%	73.3%	71.2%	71.4%	76.0%
	80	87.1%	86.8%	88.6%	89.1%	88.0%	88.8%	95.5%	94.2%	90.6%
	60	90.0%	89.2%	89.4%	96.8%	95.3%	92.0%	91.6%	90.0%	88.3%
	40	100.0%	100.0%	97.1%	100.0%	100.0%	96.3%	99.9%	100.0%	94.5%
	30	100.0%	100.0%	95.1%	100.0%	100.0%	98.0%	100.0%	100.0%	98.2%

Table 13.10: Percentage of products within x days per WIP level, given priority and maximal throughput time,90%

Nr of days r	WIPlevel	15000 % products late		20000 % products late		30000 % products late	
10	130	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%
	100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	130	1.0%	0.0%	4.2%	1.5%	5.7%	3.9%
	100	1.3%	0.1%	0.0%	0.0%	0.0%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	130	7.9%	3.7%	16.7%	11.9%	18.0%	15.4%
	100	8.7%	4.7%	1.8%	0.4%	4.5%	1.8%
	80	2.0%	0.7%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	130	26.5%	20.8%	37.2%	34.6%	37.7%	35.1%
	100	29.3%	23.2%	18.9%	9.2%	20.3%	13.1%
	80	16.0%	8.7%	2.6%	0.4%	1.3%	0.0%
	60	0.0%	0.0%	1.1%	0.0%	2.5%	0.7%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 13.11: Percentage of products late per WIP level, given priority and maximal throughput time, 70%

Nr of days r	WIPlevel	15000 1 day % products within x days	 5 days 	20000 1 day % products within x days	 5 days 	30000 1 day % products within x days	 5 days
10	130	100.0%	98.0%	99.6%	94.4%	98.8%	93.1%
	100	100.0%	97.6%	100.0%	99.7%	100.0%	99.0%
	80	100.0%	99.6%	100.0%	100.0%	100.0%	100.0%
	60	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
8	130	95.6%	85.2%	89.7%	81.4%	87.6%	80.6%
	100	95.7%	84.1%	99.5%	88.2%	98.5%	88.0%
	80	99.3%	89.6%	100.0%	98.2%	100.0%	99.1%
	60	100.0%	99.6%	100.0%	99.2%	99.9%	98.2%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
6	130	82.3%	76.1%	69.6%	71.6%	69.8%	70.1%
	100	80.9%	75.3%	91.7%	78.3%	88.4%	78.1%
	80	92.3%	77.1%	99.5%	82.8%	99.8%	84.8%
	60	100.0%	91.2%	99.9%	83.9%	99.0%	82.9%
	40	100.0%	99.1%	100.0%	99.6%	100.0%	95.5%
	30	100.0%	98.9%	100.0%	96.5%	100.0%	99.6%
4	130	54.7%	71.7%	44.3%	57.2%	44.3%	56.4%
	100	52.3%	70.2%	63.2%	74.5%	62.8%	72.4%
	80	66.9%	74.6%	87.0%	78.9%	93.3%	79.7%
	60	97.5%	84.5%	91.0%	78.6%	88.7%	78.0%
	40	100.0%	96.1%	99.9%	97.1%	99.2%	88.3%
	30	99.9%	95.4%	99.5%	90.2%	100.0%	97.7%

Table 13.12: Percentage of products within x days per WIP level, given priority and maximal throughput time,70%

13.1.3.4: Normal value distribution, low processing times

		20000			15000			30000		
		FCFS	1 day	5 days	FCFS	1 day	5 days	FCFS	1 day	5 days
max days	WIPlevel	% products	% products	% products	% products	% products	% products	% products	% products	% products
10	130	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%
	100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	130	1.9%	1.4%	0.9%	1.9%	1.4%	0.9%	5.6%	4.6%	3.5%
	100	0.2%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	130	12.4%	10.6%	8.5%	11.3%	10.3%	8.4%	20.3%	18.9%	17.0%
	100	3.6%	2.8%	1.8%	2.0%	1.5%	1.0%	3.0%	2.4%	1.3%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	130	38.3%	36.9%	35.8%	36.3%	34.9%	32.7%	42.4%	40.9%	41.9%
	100	25.6%	24.0%	19.9%	14.6%	13.1%	10.1%	20.2%	17.4%	14.7%
	80	1.5%	1.0%	0.3%	2.8%	1.7%	0.9%	1.6%	1.2%	0.6%
	60	1.2%	0.0%	0.2%	0.2%	0.0%	0.0%	4.0%	0.0%	2.2%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 13.13: Percentage of products late per WIP level, given priority and maximal throughput time, 90%

		20000			15000			30000		
		FCFS	1 day	5 days	FCFS	1 day	5 days	FCFS	1 day	5 days
max days	WIPlevel	% products	% products	% products	% products	% products	% products	% products	% products	% products
10	130	100.0%	100.0%	98.4%	100.0%	100.0%	98.6%	99.8%	99.8%	97.3%
	100	100.0%	100.0%	99.6%	100.0%	100.0%	99.8%	100.0%	100.0%	99.7%
	80	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	60	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.8%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
8	130	97.9%	97.9%	92.8%	97.9%	97.7%	93.4%	93.8%	93.7%	90.6%
	100	99.8%	99.8%	94.5%	99.9%	99.8%	96.1%	100.0%	99.9%	95.2%
	80	100.0%	100.0%	98.8%	100.0%	100.0%	98.3%	100.0%	100.0%	99.1%
	60	100.0%	100.0%	98.7%	100.0%	100.0%	99.7%	100.0%	100.0%	98.1%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
6	130	86.3%	85.9%	84.5%	87.4%	86.5%	84.9%	77.5%	77.1%	77.2%
	100	96.1%	95.3%	89.9%	97.8%	97.6%	91.2%	96.7%	96.2%	91.0%
	80	100.0%	100.0%	93.3%	100.0%	100.0%	92.5%	99.9%	99.9%	93.5%
	60	100.0%	100.0%	92.9%	100.0%	100.0%	94.8%	100.0%	99.8%	92.7%
	40	100.0%	100.0%	99.4%	100.0%	100.0%	98.7%	100.0%	100.0%	95.9%
	30	100.0%	100.0%	97.6%	100.0%	100.0%	99.5%	100.0%	100.0%	99.2%
4	130	57.5%	56.8%	60.3%	59.6%	59.2%	63.6%	53.2%	53.4%	54.8%
	100	70.9%	69.7%	74.2%	82.6%	82.2%	83.4%	77.5%	77.4%	79.2%
	80	98.3%	96.9%	92.3%	96.9%	95.4%	91.2%	98.2%	97.2%	92.3%
	60	98.7%	97.0%	91.9%	99.7%	99.1%	93.9%	95.5%	94.3%	90.4%
	40	100.0%	100.0%	98.5%	100.0%	100.0%	97.5%	99.8%	99.4%	94.9%
	30	100.0%	99.9%	96.3%	100.0%	100.0%	98.9%	100.0%	100.0%	98.3%

Table 13.14: Percentage of products within x days per WIP level, given priority and maximal throughput time,90%

		15000		20000		30000	
		1 day	5 days	1 day	5 days	1 day	5 days
Nr of days ı	WIPlevel: 1	% products late		% products late		% products late	
10	130	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8	130	0.7%	0.2%	0.3%	0.0%	1.5%	0.7%
	100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6	130	7.4%	3.7%	5.6%	1.3%	7.0%	4.5%
	100	0.0%	0.0%	0.0%	0.0%	0.3%	0.1%
	80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4	130	23.2%	17.9%	24.2%	17.9%	25.6%	18.2%
	100	6.1%	1.5%	3.3%	0.8%	6.1%	1.5%
	80	2.4%	0.6%	1.5%	0.3%	0.6%	0.1%
	60	0.0%	0.0%	0.8%	0.2%	0.7%	0.0%
	40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	30	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 13.15: Percentage of products late per WIP level, given priority and maximal throughput time, 70%

Nr of days n	WIPlevel	15000 1 day	 5 days	20000 1 day	 5 days	30000 1 day	 5 days
		% products within x days		% products within x days		% products within x days	
10	130	100.0%	98.2%	99.2%	100.0%	97.9%	99.9%
	100	100.0%	100.0%	100.0%	100.0%	99.9%	100.0%
	80	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	60	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
8	130	97.0%	87.6%	86.3%	98.4%	85.7%	96.1%
	100	100.0%	96.4%	97.7%	100.0%	96.0%	99.9%
	80	100.0%	98.5%	99.1%	100.0%	99.6%	100.0%
	60	100.0%	100.0%	99.4%	100.0%	99.4%	100.0%
	40	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	30	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
6	130	84.4%	75.3%	76.9%	86.1%	76.2%	84.7%
	100	98.5%	81.3%	82.8%	99.5%	82.5%	98.2%
	80	99.3%	86.0%	87.7%	99.6%	87.4%	99.9%
	60	100.0%	99.8%	89.0%	99.8%	86.7%	99.8%
	40	100.0%	100.0%	100.0%	100.0%	97.0%	100.0%
	30	100.0%	99.8%	98.2%	100.0%	100.0%	100.0%
4	130	59.9%	71.6%	70.5%	57.5%	70.8%	56.4%
	100	82.5%	77.7%	77.9%	86.7%	78.6%	82.1%
	80	90.8%	80.1%	82.2%	93.5%	81.6%	94.7%
	60	100.0%	98.5%	81.8%	94.8%	81.0%	93.5%
	40	100.0%	98.7%	99.6%	100.0%	91.2%	99.6%
	30	100.0%	97.8%	92.2%	100.0%	98.9%	100.0%

Table 13.16: Percentage of products within x days per WIP level, given priority and maximal throughput time,70%

Appendix 13.2. Results for Design 2

The graphs display the total sales value of the products repaired on time per WIP level used for control. The graphs cover the full year of observations. The terminology used is identical to the terminology in the previous section.

Due to the different draws from the arrival distribution the lines in the graphs can cross, since then lower values can be attained in the simulation for a throughput time of a greater number of days. However, this is a consequence of the simulation and the draws from the distribution. Where this occurs, the difference is never significant. Thus higher maximum throughput times never lead to significantly lower total sales values attained then lower maximum throughput times under the same circumstances, although the lines in the figures might imply to this.

13.2.1: normal value distribution, normal processing times

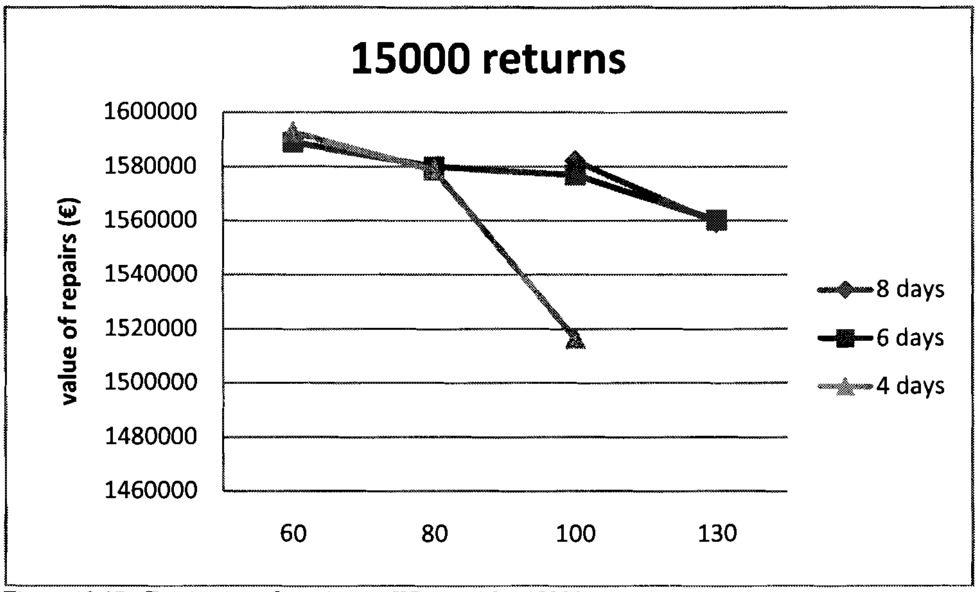


Figure 13.17.: Total value of repairs per WIPlevel for 15000 returns

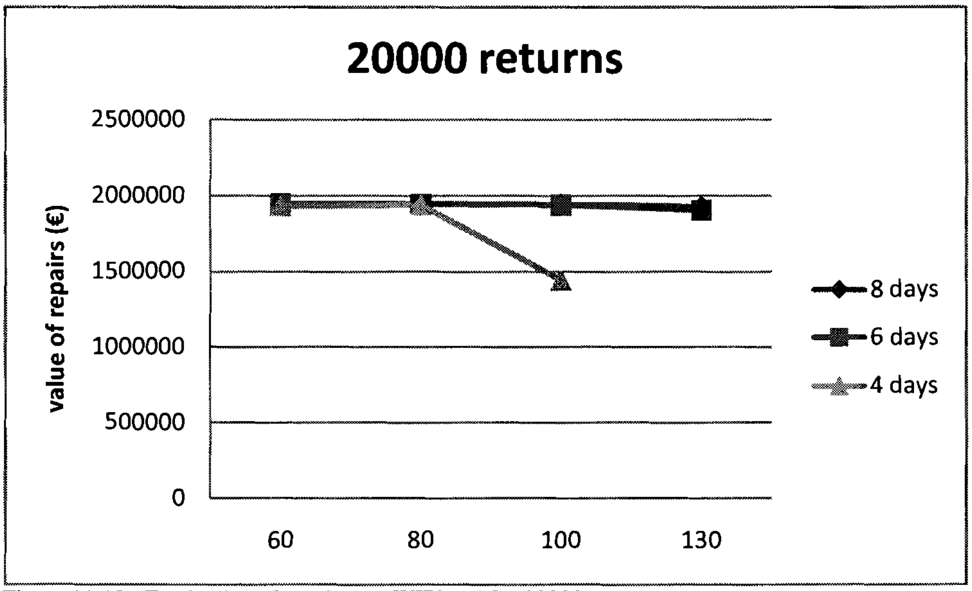


Figure 13.18.: Total value of repairs per WIPlevel for 20000 returns

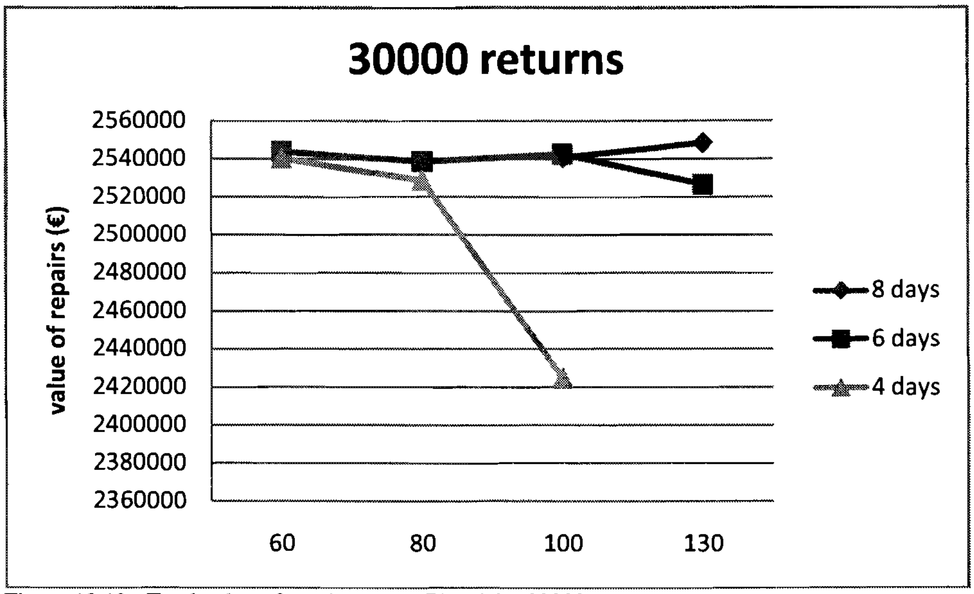


Figure 13.19.: Total value of repairs per WIPlevel for 30000 returns

13.2.2: high value distribution, normal processing times

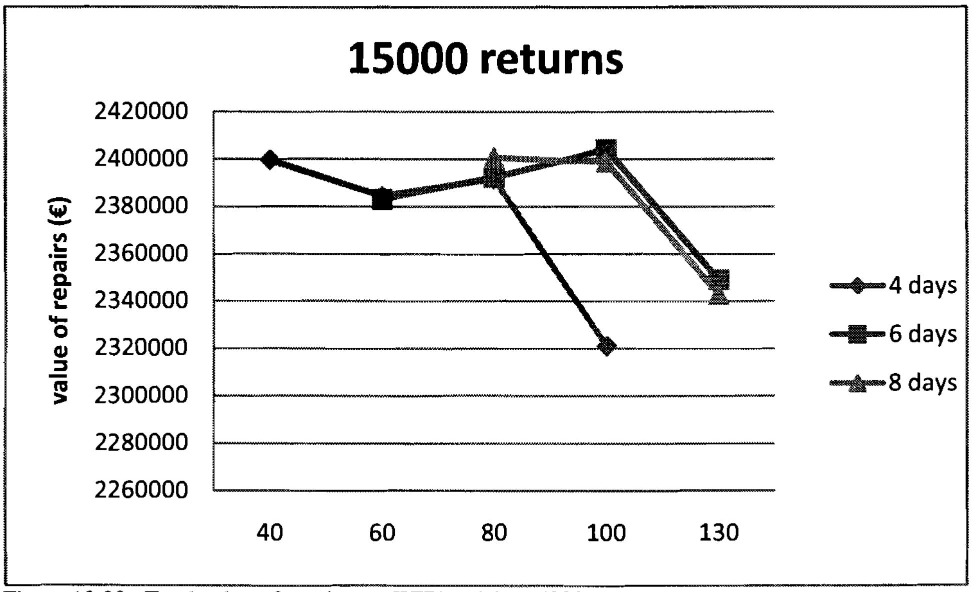


Figure 13.20.: Total value of repairs per WIPlevel for 15000 returns

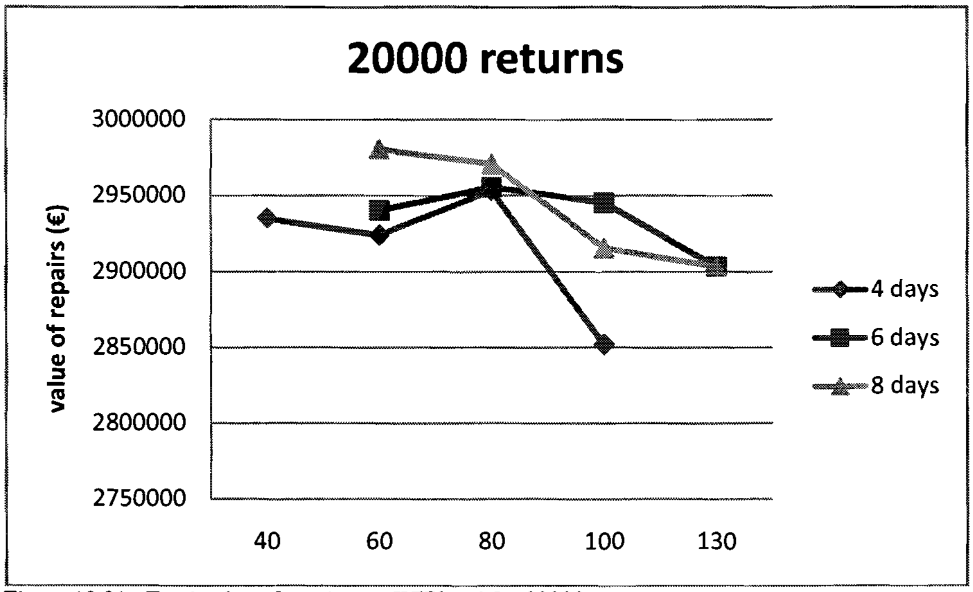


Figure 13.21.: Total value of repairs per WIPlevel for 20000 returns

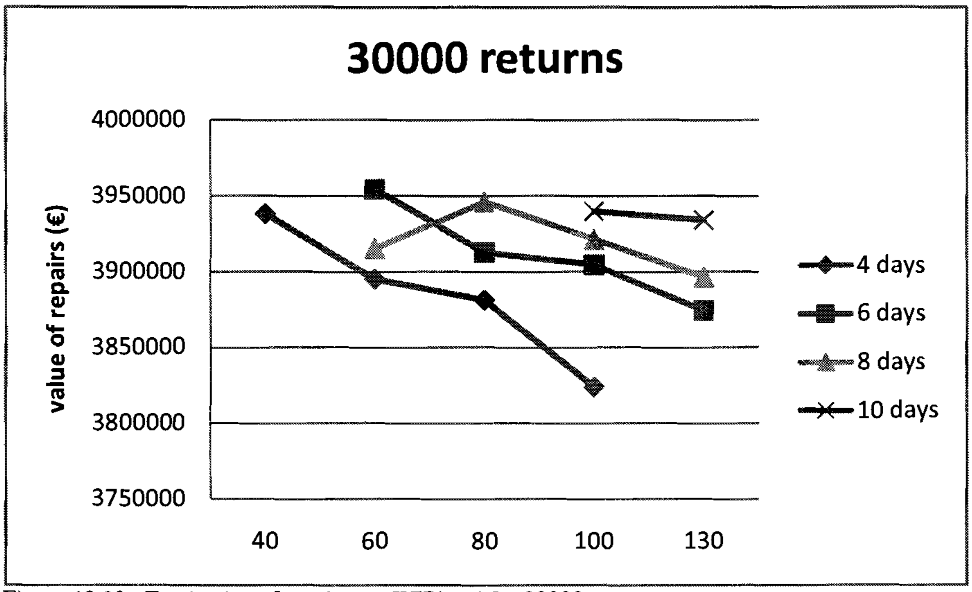


Figure 13.22.: Total value of repairs per WIPlevel for 30000 returns

13.2.3: low value distribution, normal processing times

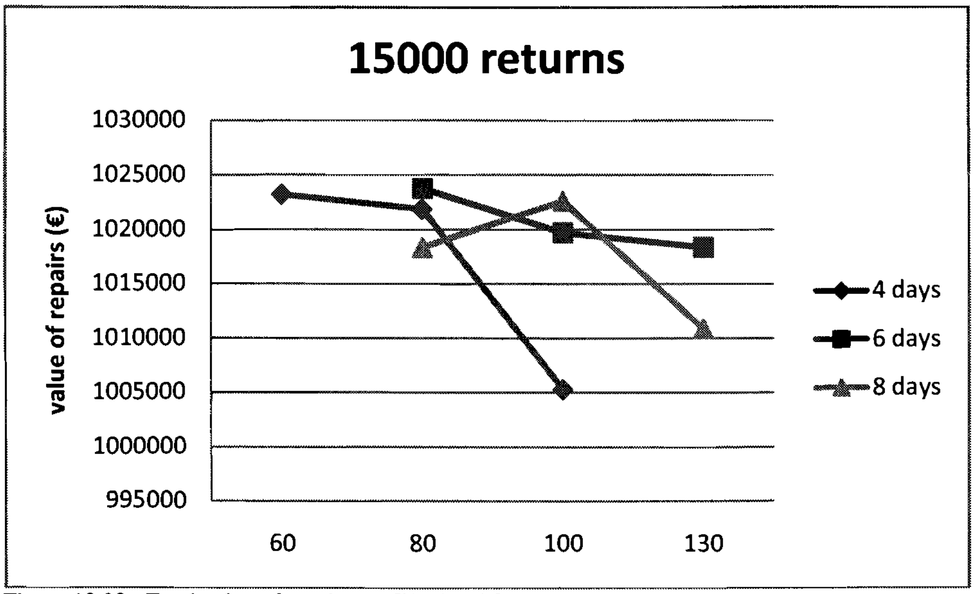


Figure 13.23.: Total value of repairs per WIPlevel for 15000 returns

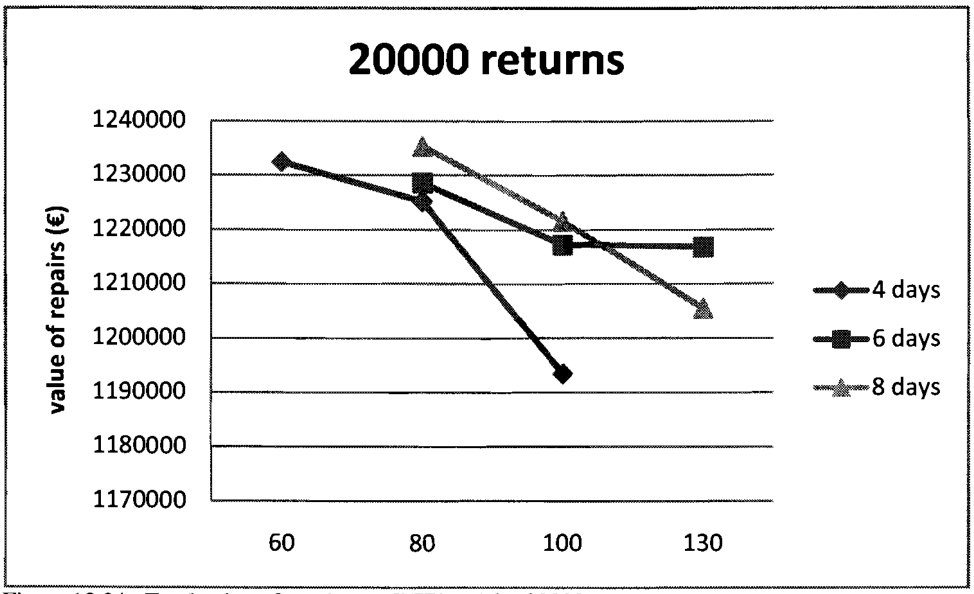


Figure 13.24.: Total value of repairs per WIPlevel for 20000 returns

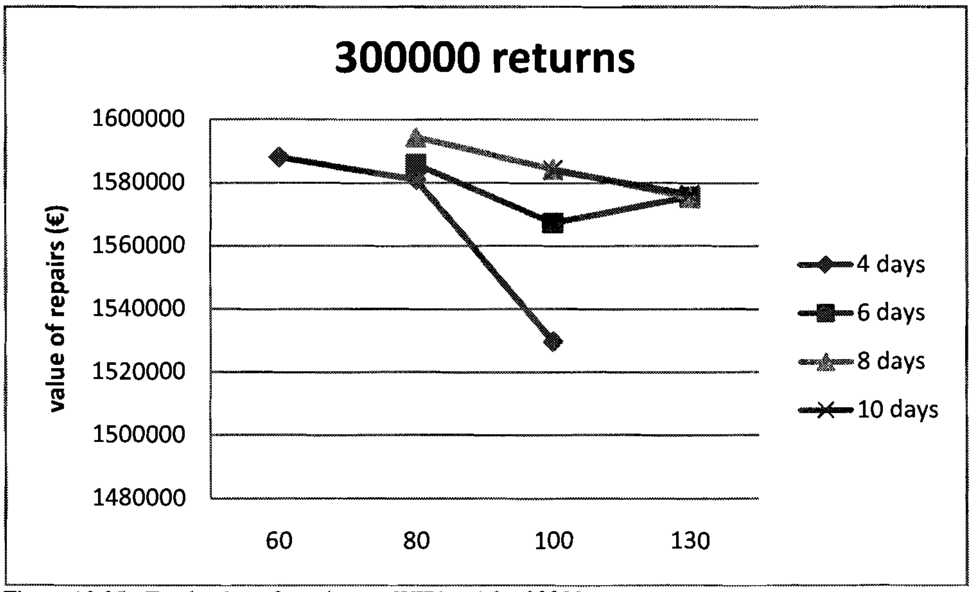


Figure 13.25.: Total value of repairs per WIPlevel for 30000 returns

13.2.4: normal value distribution, low processing times

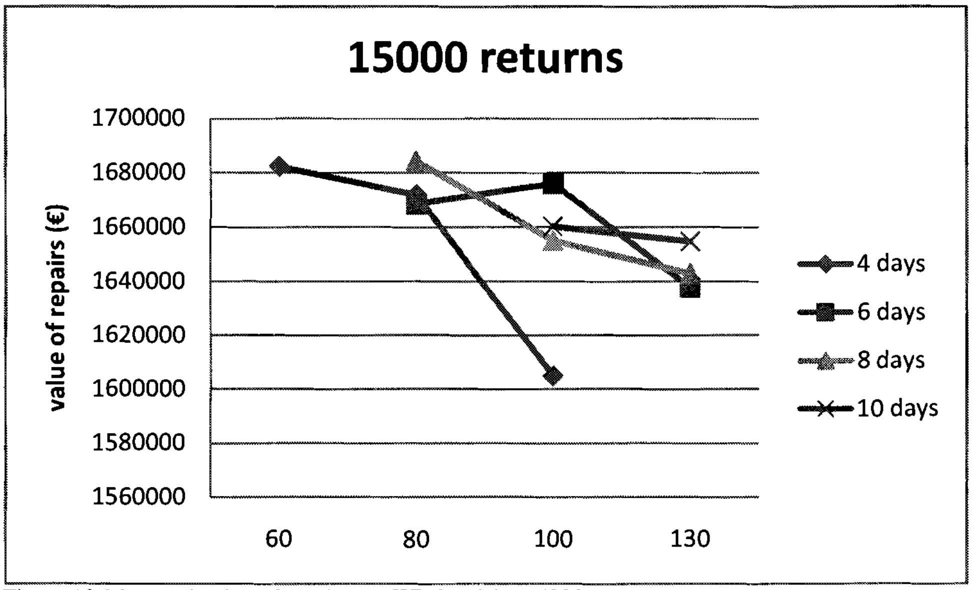


Figure 13.26.: Total value of repairs per WIPlevel for 15000 returns

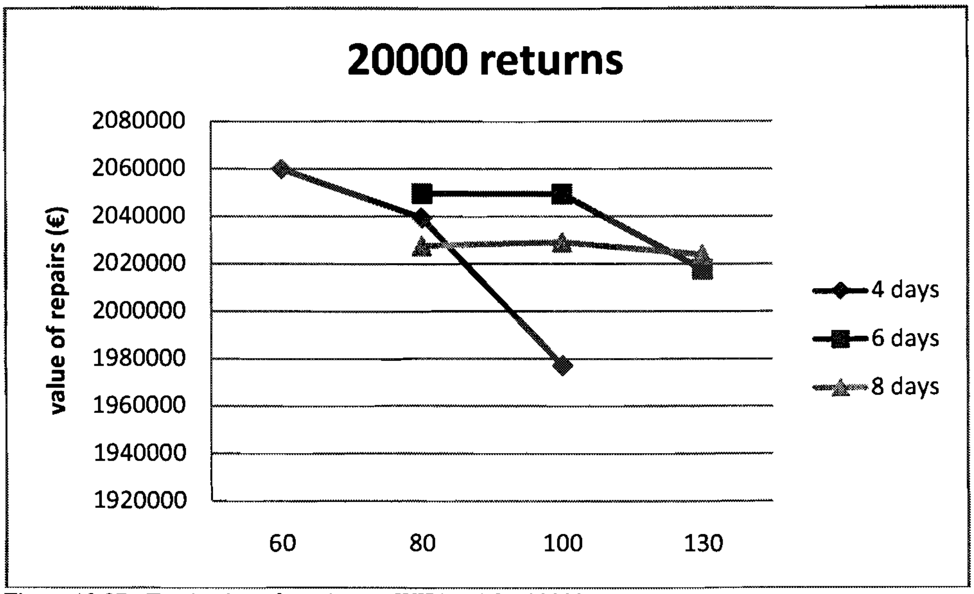


Figure 13.27.: Total value of repairs per WIPlevel for 20000 returns

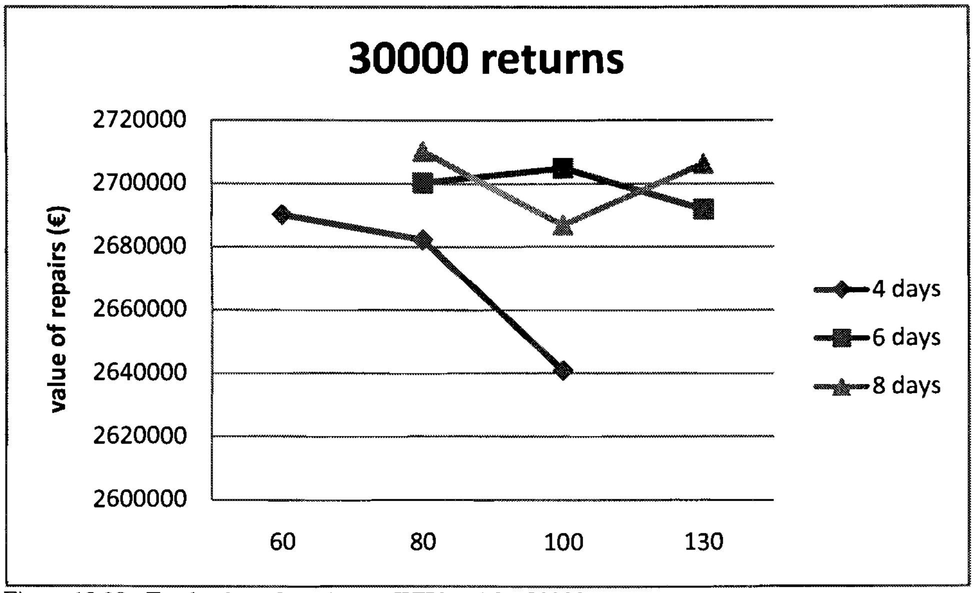


Figure 13.28.: Total value of repairs per WIPlevel for 30000 returns

Appendix 13.3. Results for Design 3

The graphs display the total sales value of the products repaired on time per WIP level used for control. The graphs cover the full year of observations. The terminology used is identical to the terminology in the previous section.

Due to the different draws from the arrival distribution in different simulation runs, the lines in the graphs can cross, since then lower values can be attained in the simulation for a throughput time of a greater number of days. However, this is a consequence of the simulation and the draws from the distribution. Where this occurs, the difference is never significant. Thus higher maximum throughput times never lead to significantly lower total sales values attained then lower maximum throughput times under the same circumstances, although the lines in the figures might imply to this.

13.3.1: normal value distribution, normal processing times

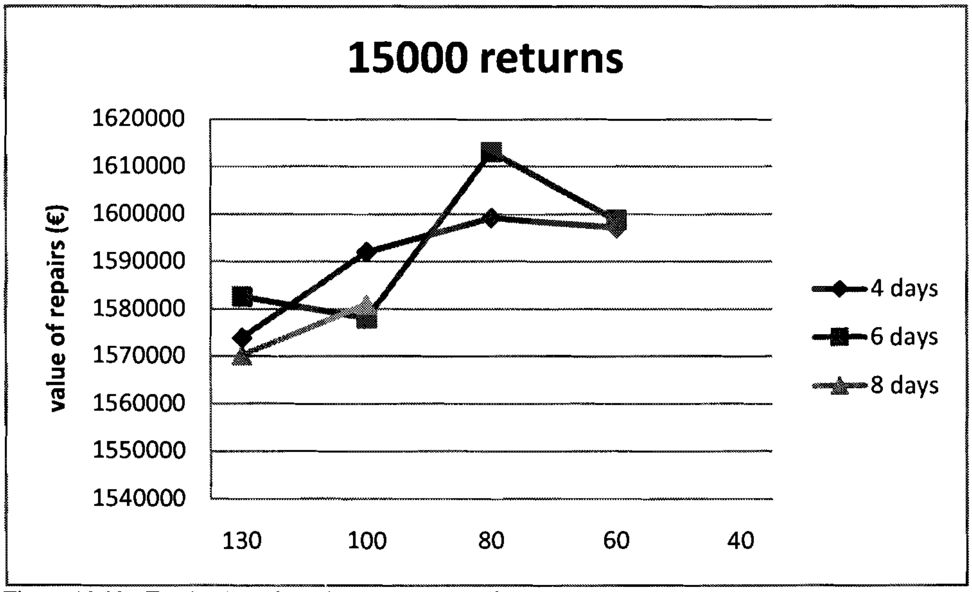


Figure 13.29.: Total value of repairs per WIPlevel for 15000 returns

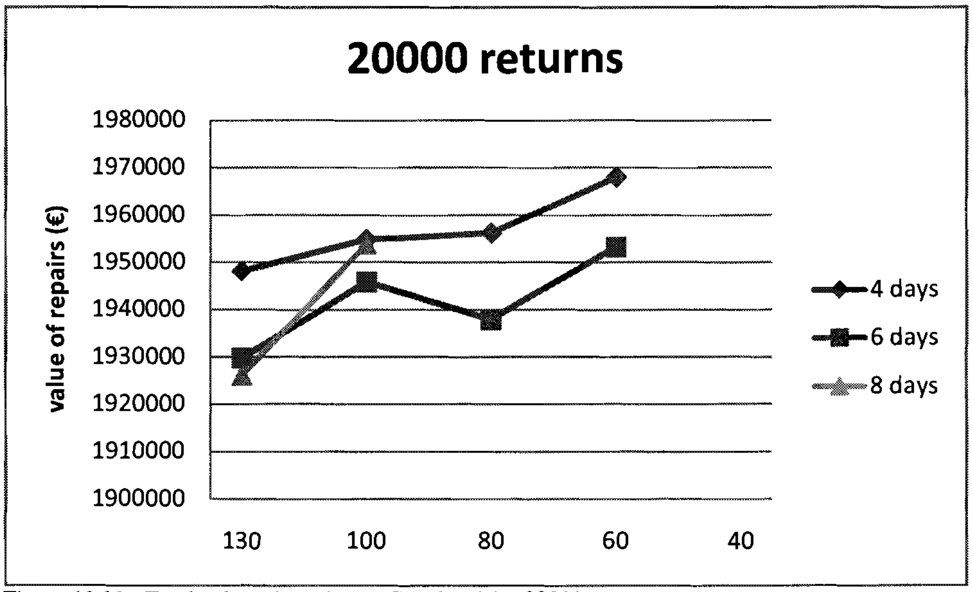


Figure 13.30.: Total value of repairs per WIPlevel for 20000 returns

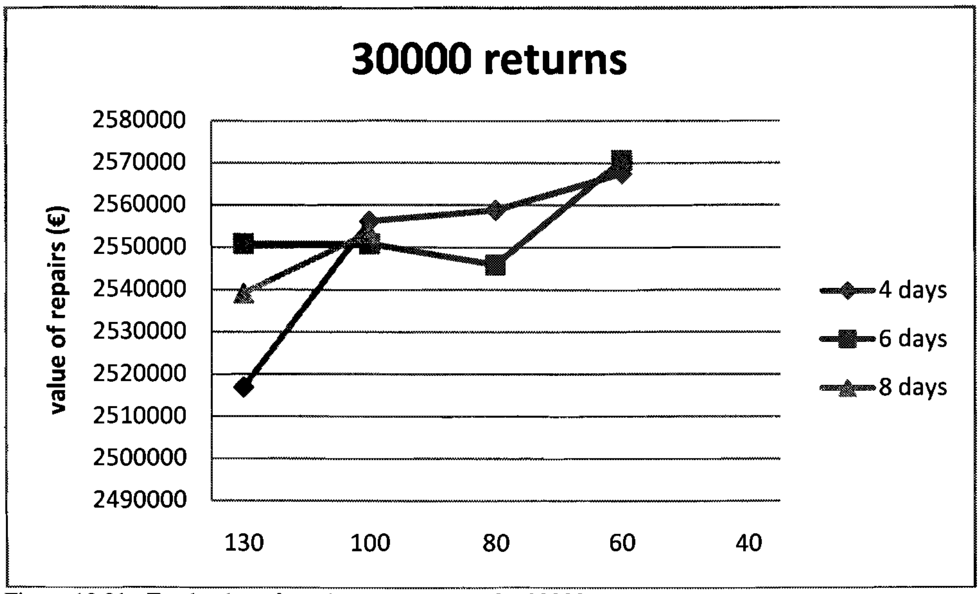


Figure 13.31.: Total value of repairs per WIPlevel for 30000 returns

13.3.2: high value distribution, normal processing times

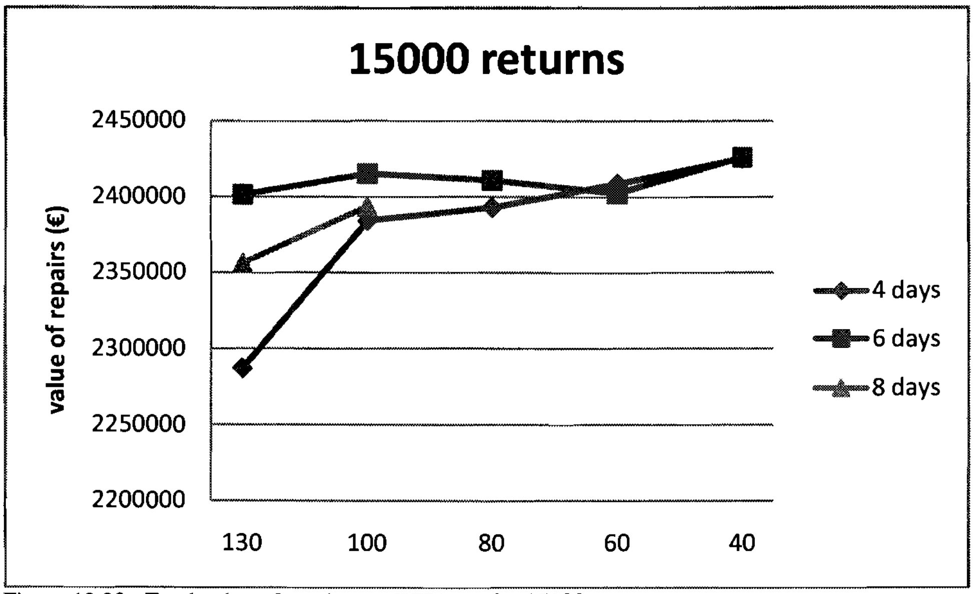


Figure 13.32.: Total value of repairs per WIPlevel for 15000 returns

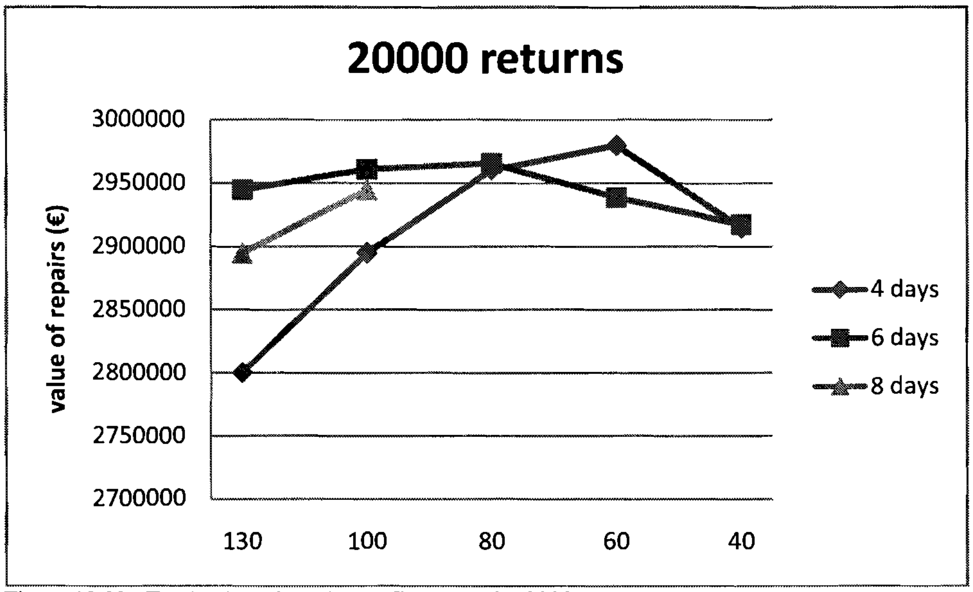


Figure 13.33.: Total value of repairs per WIPlevel for 20000 returns

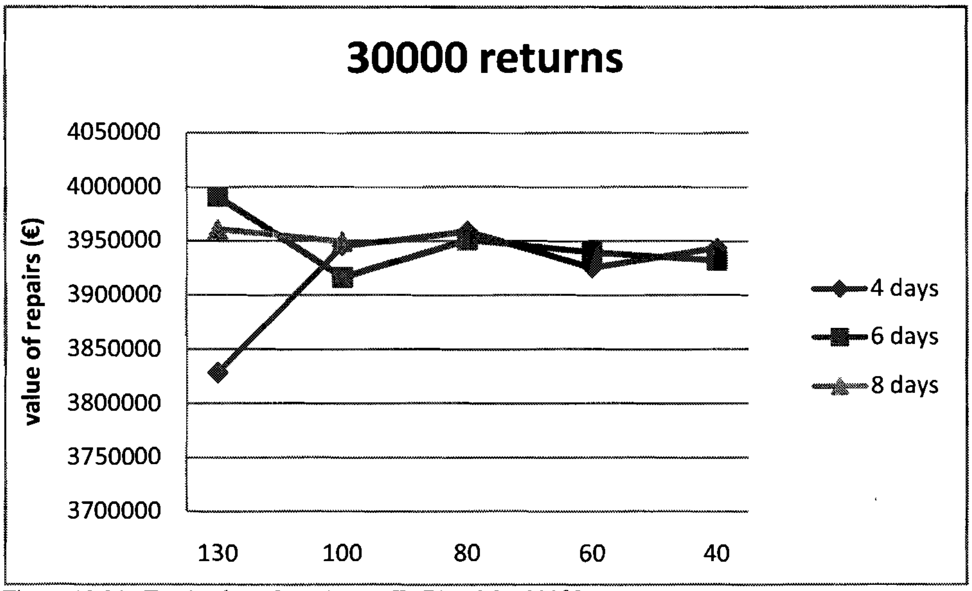


Figure 13.34.: Total value of repairs per WIPlevel for 30000 returns

13.3.3: low value distribution, normal processing times

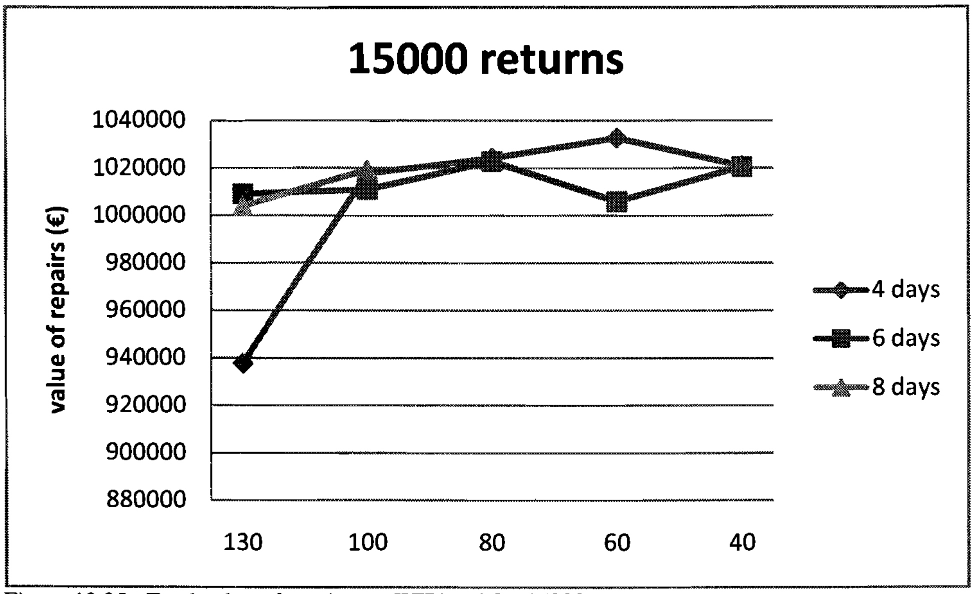


Figure 13.35.: Total value of repairs per WIPlevel for 15000 returns

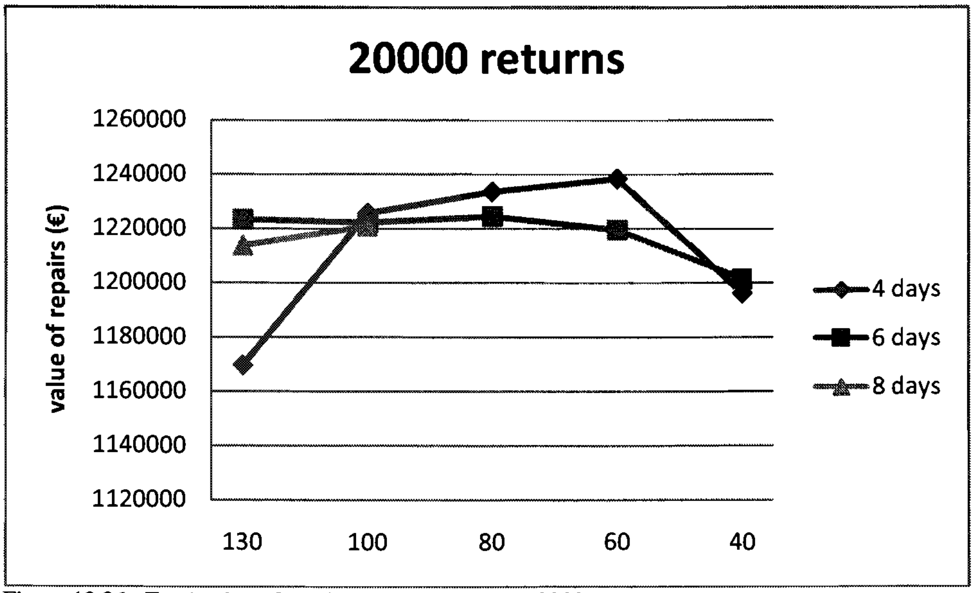


Figure 13.36.: Total value of repairs per WIPlevel for 20000 returns

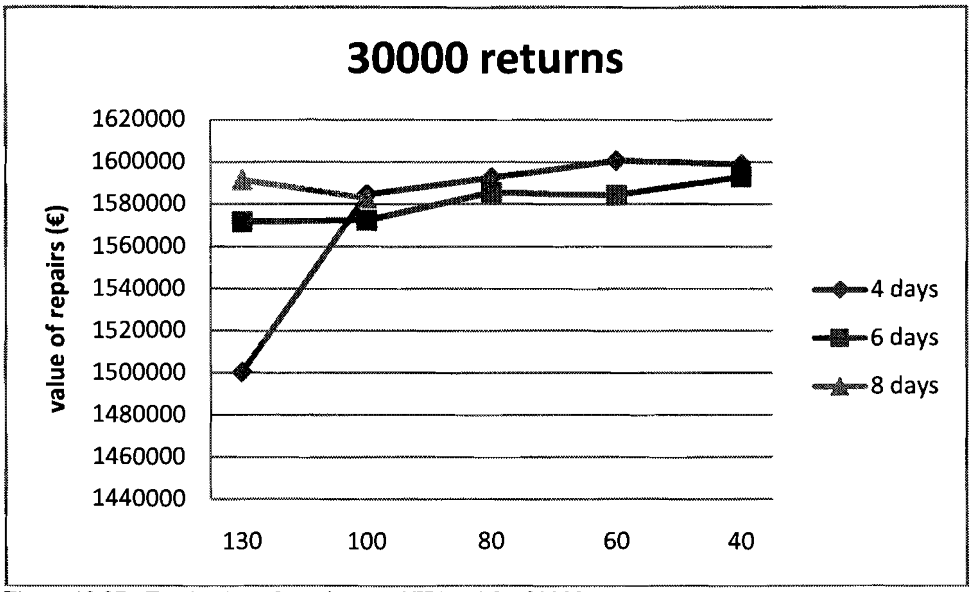


Figure 13.37.: Total value of repairs per WIPlevel for 30000 returns

13.3.3: normal value distribution, low processing times

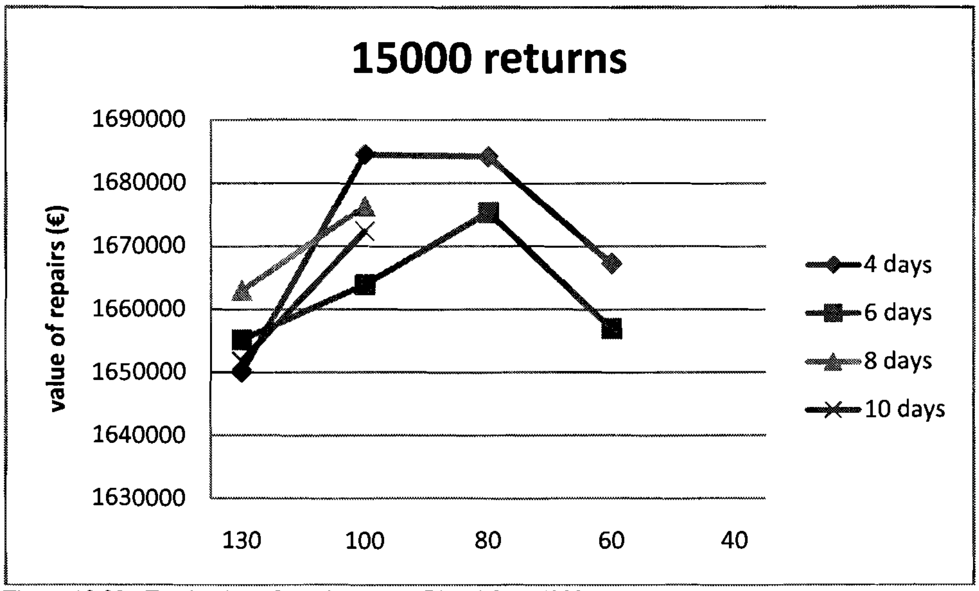


Figure 13.38.: Total value of repairs per WIPlevel for 15000 returns

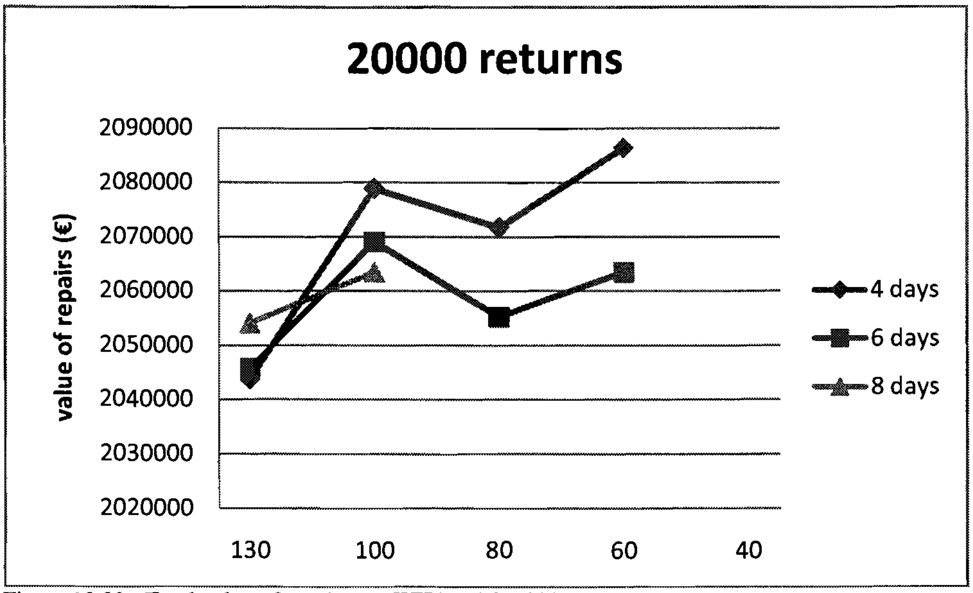


Figure 13.39.: Total value of repairs per WIPlevel for 20000 returns

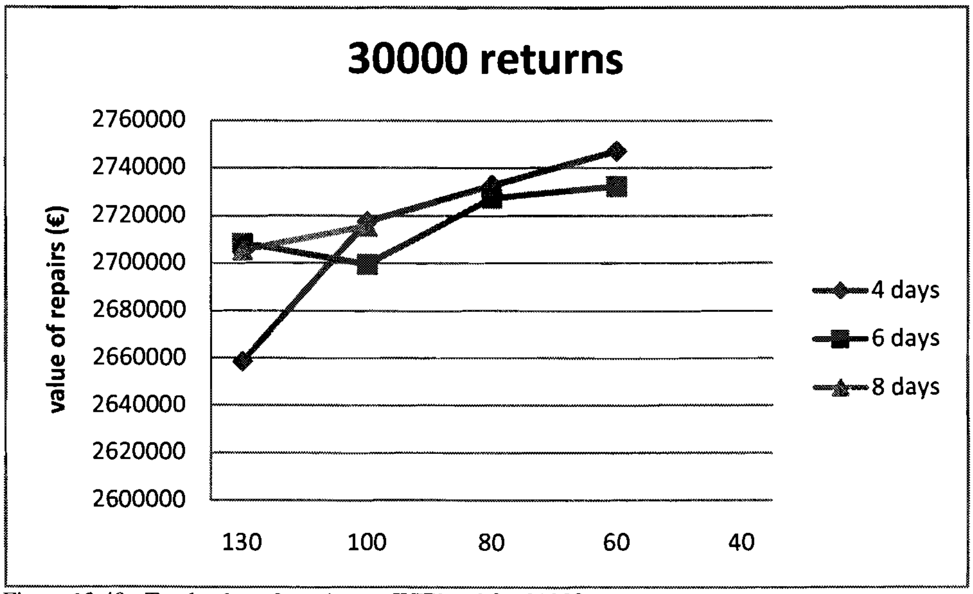


Figure 13.40.: Total value of repairs per WIPlevel for 30000 returns

Appendix 13.4: Result for design 1-3

Returns per year:	15000	20000	30000
Nr of days maximum	Total value	Total value	Total value
normal value distribution, normal processing times			
4	97.8%	98.3%	97.3%
6	98.7%	97.6%	97.4%
8	96.7%	97.6%	96.8%
10	98.2%	97.1%	96.4%
high value distribution, normal processing times			
4	96.5%	95.8%	94.9%
6	96.5%	95.4%	95.7%
8	95.2%	94.7%	95.0%
10	95.3%	96.1%	94.6%
low value distribution, normal processing times			
4	99.6%	98.1%	99.1%
6	98.6%	97.0%	98.6%
8	98.3%	96.7%	98.5%
10	99.5%	97.6%	98.6%
normal value distribution, low processing times			
4	99.9%	98.8%	98.9%
6	98.2%	98.0%	98.4%
8	98.3%	97.7%	97.8%
10	98.1%	97.6%	97.4%

Table 13.17: Percentages of the upper bound for designs 1-3

Appendix 15: Results for varying capacity for design 3

The figures show the relation between total sales value of the repaired products in euro (y-axis) and the WIPlevel used for control in products (x-axis).

Appendix 15.1: normal value distribution, normal processing times

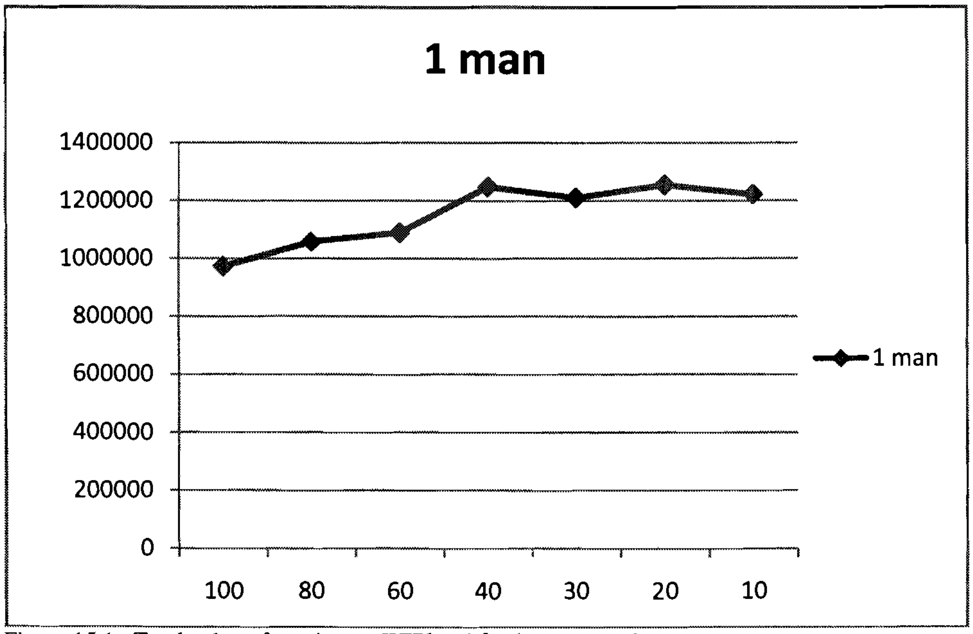


Figure 15.1.: Total value of repairs per WIPlevel for 1 man capacity

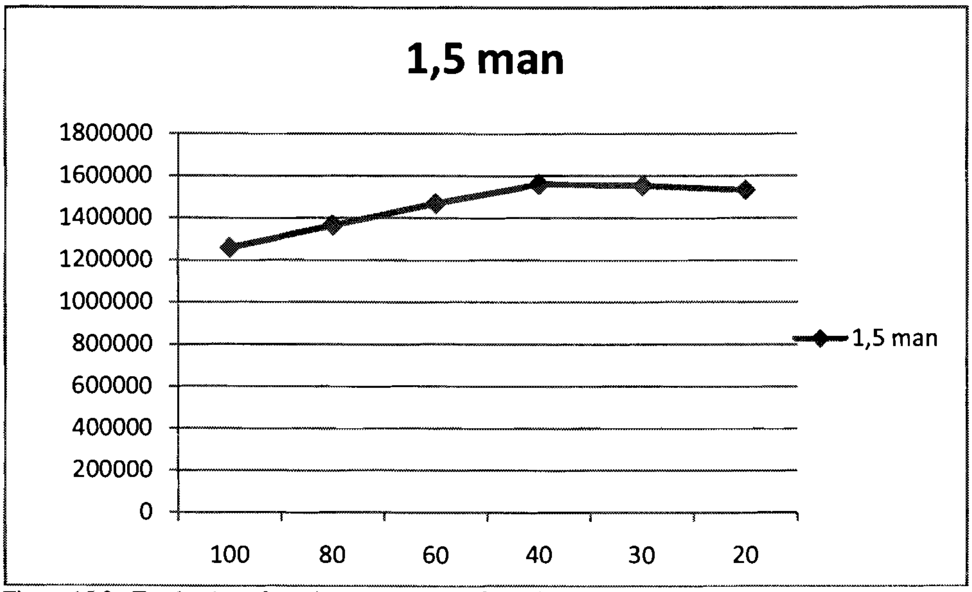


Figure 15.2.: Total value of repairs per WIPlevel for 1,5 men capacity

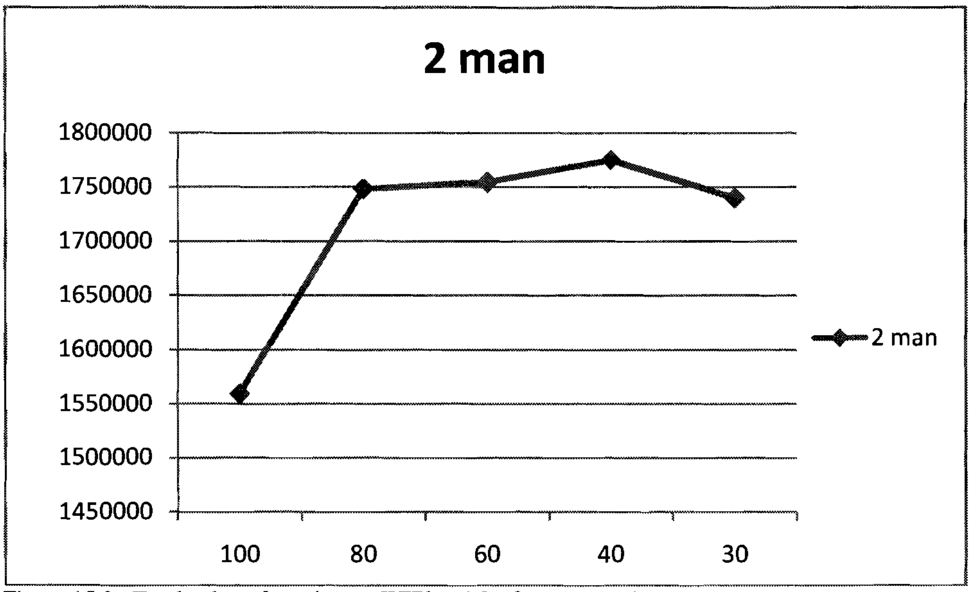


Figure 15.3.: Total value of repairs per WIPlevel for 2 men capacity

Appendix 15.2: high value distribution, normal processing times

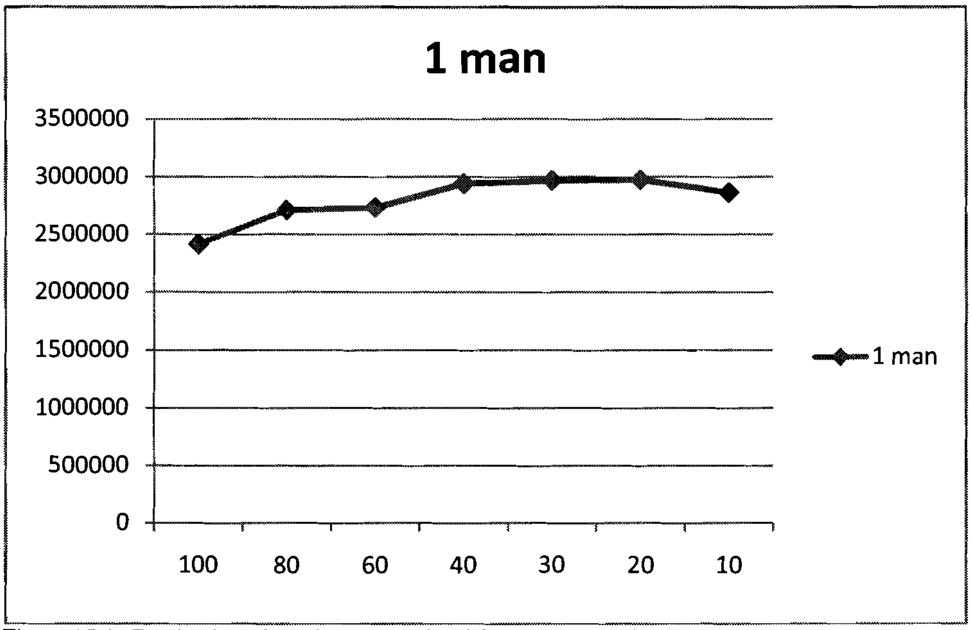


Figure 15.4.: Total value of repairs per WIPlevel for 1 man capacity

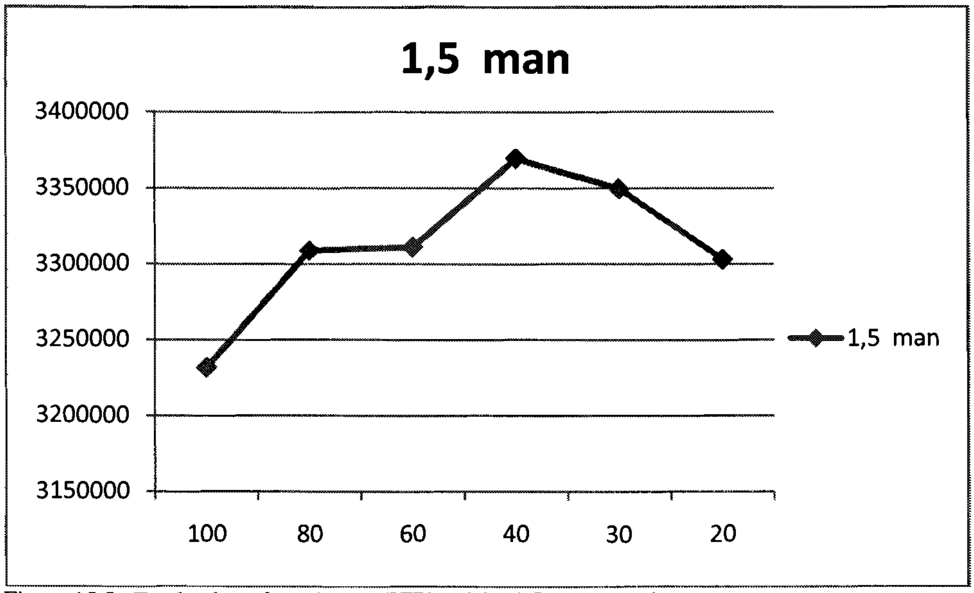


Figure 15.5.: Total value of repairs per WIPlevel for 1,5 men capacity

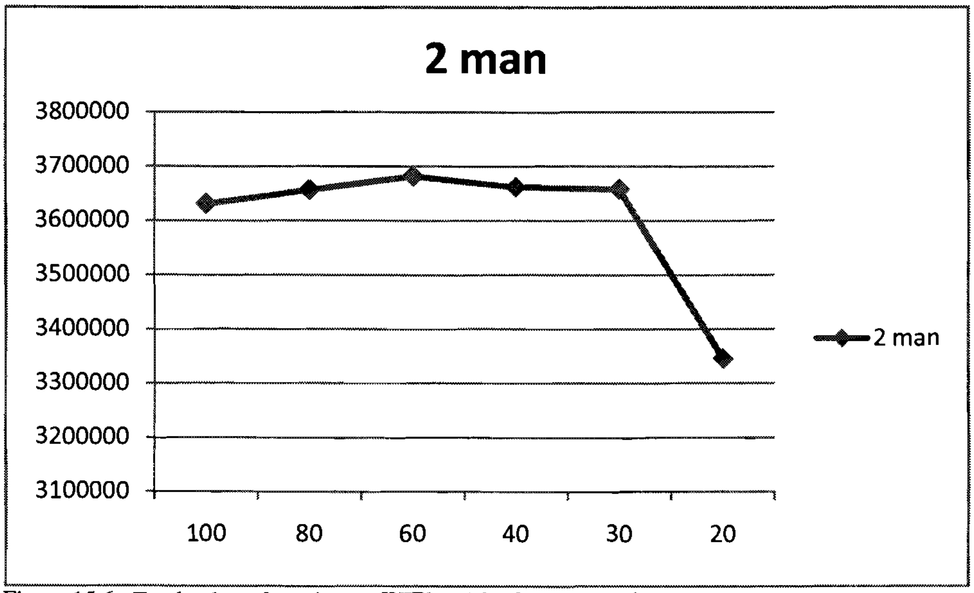


Figure 15.6.: Total value of repairs per WIPlevel for 2 men capacity

Appendix 15.3: low value distribution, normal processing times

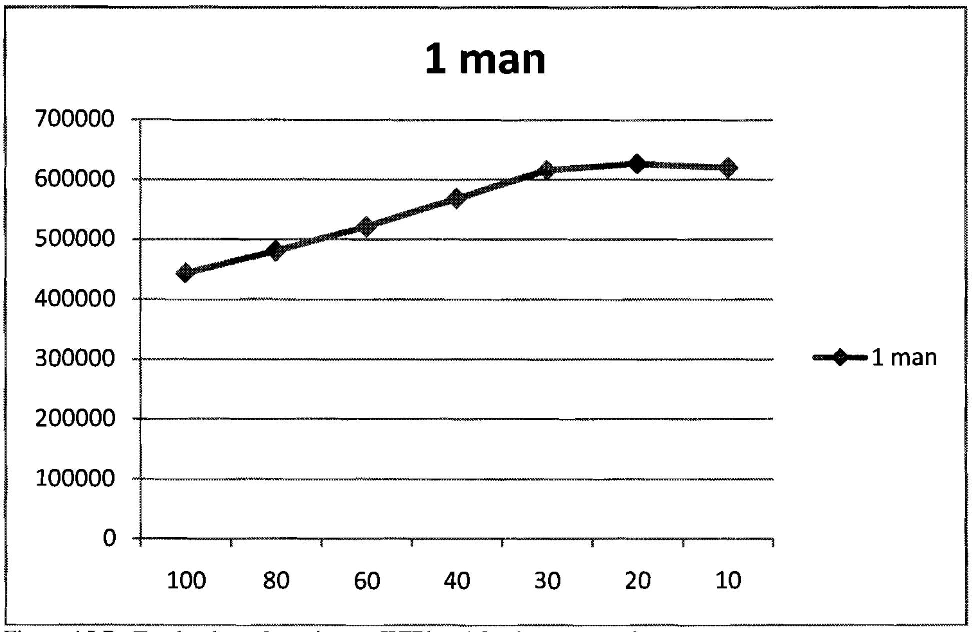


Figure 15.7.: Total value of repairs per WIPlevel for 1 man capacity

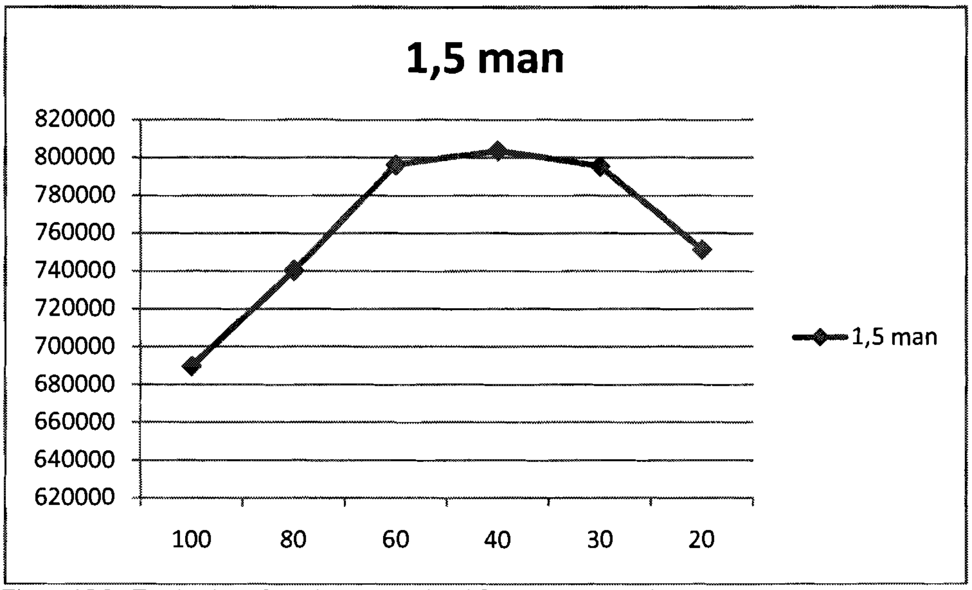


Figure 15.8.: Total value of repairs per WIPlevel for 1,5 men capacity

Figure 15.9.: Total value of repairs per WIPlevel for 2 men capacity

Appendix 16: Results for Design 4

Appendix 16.1: Upper bounds for varying handling times

Handling time: **0 min**	15000	20000	30000
normal value distribution, normal processing times	1647889	2009188	2664333
high value distribution, normal processing times	2531815	3135296	4174500
low value distribution, normal processing times	1047130	1276037	1635093
normal value distribution, low processing times	1712573	2130204	2794204
1 min	15000	20000	30000
normal value distribution, normal processing times	1636455	1988404	2642048
high value distribution, normal processing times	2510308	3112623	4129305
low value distribution, normal processing times	1036213	1264120	1613757
normal value distribution, low processing times	1697430	2101676	2763951
3 min	15000	20000	30000
normal value distribution, normal processing times	1615525	1950359	2601254
high value distribution, normal processing times	2470941	3071119	4045626
low value distribution, normal processing times	1016229	1242305	1574703
normal value distribution, low processing times	1670132	2050250	2709414
5 min	15000	20000	30000
normal value distribution, normal processing times	1588652	1916382	2564824
high value distribution, normal processing times	2435783	3026528	3928351
low value distribution, normal processing times	998382.4	1217767	1539826
normal value distribution, low processing times	1646204	2005173	2661611
7 min	15000	20000	30000
normal value distribution, normal processing times	1558264	1885855	2516892
high value distribution, normal processing times	2404195	2964432	3862345
low value distribution, normal processing times	982348	1187931	1508490
normal value distribution, low processing times	1625058	1965337	2619366
9 min	15000	20000	30000
normal value distribution, normal processing times	1530812	1858278	2461746
high value distribution, normal processing times	2375659	2907690	3802028
low value distribution, normal processing times	967862	1160978	1480181
normal value distribution, low processing times	1600755	1929879	2581764

Table 16.1: Upper bounds on the total value of repairs for design 4 under different handling times