Table of Contents

Go Back

Analyses of a repair cycle in a high-tech company with System Dynamics Methodology

Dipl.-Ing. Claudia Dingethal
University of Bergen/Norway
Wallaustrasse 58, 55118 Mainz/Germany
Phone: +49 (0) 163 / 47 567 49
E-mail: dingethal@gmx.de

Abstract

During the last years the demand on companies concerning product-life-cycle-management grew because of strict environmental laws and an increasing world-wide competition. Repair cycles have been established in the industry and in the military in order to support a sustainable development in environmental and economical aspects. This paper presents a client project in which the repair cycle of a high-tech company was analysed using System Dynamics Methodology. The company detected high inefficiencies in respect to capital lockup and storage costs due to long and varying time delays in shipment processes. In order to enhance cost efficiency and customer satisfaction, it was important to represent and understand structure and dynamic behaviour of the repair cycle. The System Dynamics model allows analysing consequences of changes in time characteristics. Major insights could be gained about the behaviour of the repair cycle during the transient phase but also in respect to long term effects.

Keywords: Repair Cycle, Material flow, product-life-cycle, logistics

1. Introduction

During the last years the demand on companies concerning product-life-cycle-management grew because of an extensive passing of new environmental laws and an increasing world wide competition. Companies face this challenge by developing and implementing new concepts in terms of renewing, restructuring and adjustment.

A few years ago manufacturers were responsible only for their product until it was sold and delivered to a customer. Nowadays, they are responsible for the whole life cycle of their product, including the period of life after being discarded. In other words: companies are responsible for a sustainable development in economical and environmental aspects.[1] This can be transferred into action in different ways by using the same resources several times. This work deals in particular with the option of repair cycles.

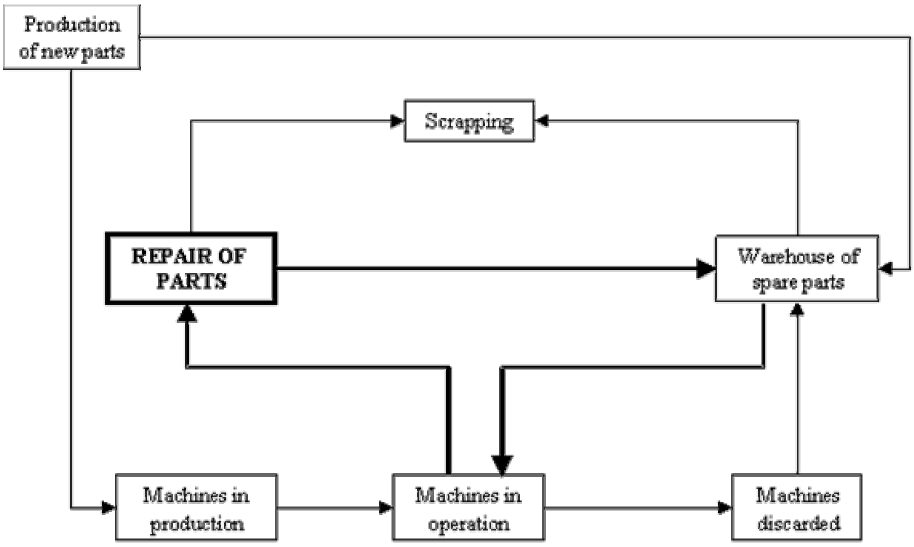

Figure 1: Elements of a general spare part logistics system[2]

In many fields of the industry and in the military, repair cycles have been established. Yet, still they have a low presence in scientific literature. A reason for that was given by REITH: "Things that had to be repaired, were defective, not used or damaged, did not suit a culture that stands for stability, durability and solidity."[3]

In this project the logistical system of a repair cycle in a high-tech company was analysed comprehensively. The company detected high inefficiencies in respect to capital lockup and storage costs. Reasons for that were long, varying and undefined time delays in shipment processes. In order to enhance cost efficiency and customer satisfaction, it was important to represent and understand structure and dynamic behaviour of the repair cycle.

---

[1] see Haasis, H.-D. (1999, pp. 255-256); Hansen, U. (1999, p. 15).

[2] based on Schuppert, F. (1994, p. 20). Please note that this is just a general structure and not a "Stock-and-Flow-Diagram" as seen from the System Dynamics point of view.

[3] own translation from Reith, R. (2001, p. 28).

2. Description of the case

The case deals with a company which produces and maintains highly sensitive machines. Their function is to equip boards for computers. 4,000 of them are in operation all over the world, 1,800 in Europe. Certain parts of the machines fail easily. From the present technological point it is not possible to improve their mean time before failure (MTBF: 90 days). Yet, it is possible to repair and install them several times. The replacement of the parts would cost the company about 2000 Euro per part. Economic analyses came to the result that the establishment of a repair cycle is highly cost advantageous for the company. In addition, a lower price can be offered to customers while the same guarantee as for newly produced parts can be provided because of a very good repair technology.

When purchasing one of the company's machines customers decide what class of spare parts they prefer to receive. They can choose between the classes of new spare parts and equal-to-new spare parts. When ordering equal-to-new parts, customers receive repaired parts, cannibalised parts or newly produced parts (most of the parts are repaired ones). Those newly produced parts are necessary to compensate for losses in the repair cycle, which will be specified later on. Yet, customers cannot distinguish between these three types. All are provided with the same quality, the same guarantee and the same price. Therefore, most of the customers have decided for the delivery of equal-to-new spare parts. In other words, customers have built a certain confidence into repaired spare parts throughout the last years.

The material flow of the repair cycle is represented in Figure 2. It shows the structure for the region of Europe with its main stations. All transportation activities between the stations of the repair cycle are conducted by commercial parcel services.

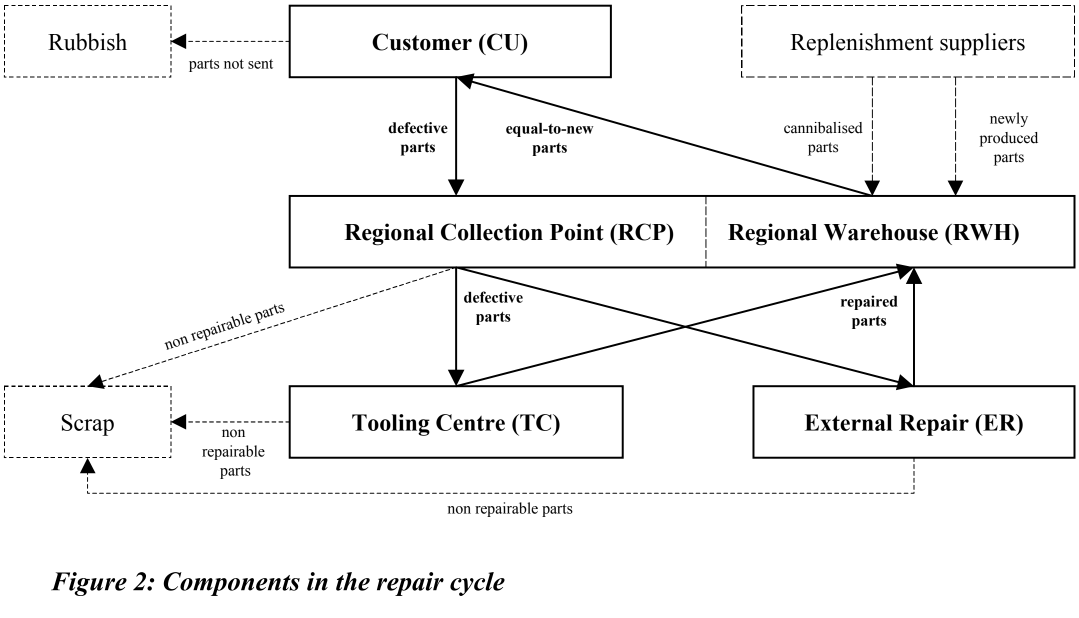

Figure 2: Components in the repair cycle

After failure of parts, customers order equal-to-new parts. They do not hold their own store, as there are too many different parts in the machines. Ordered parts are shipped from the Regional Warehouse (RWH) to customers. After receiving the ordered ones, most customers ship the broken parts to the Regional Collection Point (RCP).

Before optimizing, this process took 25 days until parts reached the RCP. Those parts cause on the one hand storage costs at the customers place and on the other hand high capital lockup. When speaking about capital lockup in parts it is referred to parts that are not in operation in any of the machines. All operating parts are necessary and therefore, do not reflect capital lockup. Yet, some customers did not send the failed parts, although they were urged to do so. They were keeping them or threw them away. Consequently, those parts were missing in the repair cycle and had to be replaced as otherwise customer orders could not be fulfilled.

The decision about a part's reparability is made in the RCP. Non-repairable parts have to be scrapped. Repairable parts are assigned to be repaired internally in one of the tooling centres (TC) or externally at external repair stations (ER). The assigning decision is just based on technical factors. No other aspect such as capacity constraints, influence the decision. After being assigned the parts are shipped to the locations with an appropriate repair order. The shipment process from RCP to the repair stations took 18 days, which was justified as too long, as well. Besides the capital lockup, storage costs for the company arose. In the TC and ER it is checked again if the parts are really repairable. Those parts found not to be repairable are scrapped, all others are repaired. Repaired parts are sent to the RWH which is, in the case of Europe, the same location as the RCP.

The material flow from customer to the RWH is consequently organised in a push system. As soon as one station finishes its job, it forwards the part to the next station. The system changes to a pull system at the RWH. That means, parts are sent to the customers when they are ordered but not earlier. As a result the RWH is working as a buffer. Moreover the RWH has to ensure certain delivery flexibility. Parts that left the repair cycle, because of not being sent or because they had to be scrapped, have to be replaced by cannibalised or newly produced parts. In addition a certain safety stock has to be ensured, in order to be able to react to unusual demand situations. For those parts a replenishment order is placed. This replenishment order is part of the information flow system. In former days it took 90 days until replenishment orders were fulfilled. This time horizon was too long and had to be shortened as well, in order to be able to react to changes in customer orders more flexible.

3. Why applying System Dynamics in this project?

In order to judge the consequences of reducing the mean lead time of the repair cycle, it was important to understand structure and behaviour of the repair cycle over time. By analysing these two components the misjudgement of feedbacks in repair cycles, resulting in the above mentioned problems of high capital lockup, high storage costs and low customer satisfaction, could be opened up. Consequently, the objective of this model was to support the general understanding of the repair cycle.

Focuses of the analysis were changes in time delays and time variance and their influence on the behaviour of the repair cycle during the transient phase and in the long run. The analysis was conducted with System Dynamics methodology as it has proven its superiority in analysing complex, dynamic, continuous and non-linear systems, like repair cycles. Specifically, in the field of logistics and material flow a large progress was made during the last years.[4] Causal loop diagrams and the physical structure of a model (stock and flow diagram) give a visible description and explanation of the relationship between main objects of the repair cycle and explain how they interact with each other.

Based on a common understanding of the structure of the repair cycle, the effect of changes at different stages of the repair cycle on the key variables could be analysed. By comparing the behaviour and results of a base run with the outcome of different single and combined policies major insights could be gained. The model, developed in this project, was used as basis for a dialogue with the customer in respect to possible improvements of the current repair cycle.

4. Causal Loop Diagrams

The power of System Dynamics is to identify important feedback structures of systems. These feedbacks can be represented with help of causal loop diagrams. Related to the problem of long time delays connected with a high capital lockup a generic causal loop diagram was developed, which is not just applicable for this specific case but for repair cycles in general. In this executive summary the focus lies on a detailed description of the feedback structure in repair cycles including replenishment ordering policies (see Figure 3):

Parts that are in operation in machines fail after a certain time. The more parts are in operation, the higher is the failure rate (failures per time), assuming a fixed time before failure. Those parts that fail are missing in the machines so that in consequence fewer parts are operating (Loop B1).

After the failure of parts, equal-to-new parts are ordered by customers and sent to them. It takes a certain time until parts arrive at the customer's place and are installed in the machines. As soon as they are installed fewer parts are missing in the machines of the customer and more are operating (Loop R1).

Until this point it is assumed that all orders can be fulfilled immediately. However, this is not always possible. For orders to be fulfilled, an adequate number of equal-to-new spare parts must be available in the company's warehouse. As long as there are less spare parts stored than ordered by customers, the appropriate number of parts cannot be sent. As soon as the warehouse is refilled more parts can be sent to meet customers' orders. Parts that were send, reduce the number of equal-to-new parts in the warehouse (Loop B2).

---

[4] Logistics was one of the major topics in the System Dynamics Conference 2000 in Bergen. Further information: Davidsen, P.I./Ford, D.N./Mashayekhi, A. N. (2000).

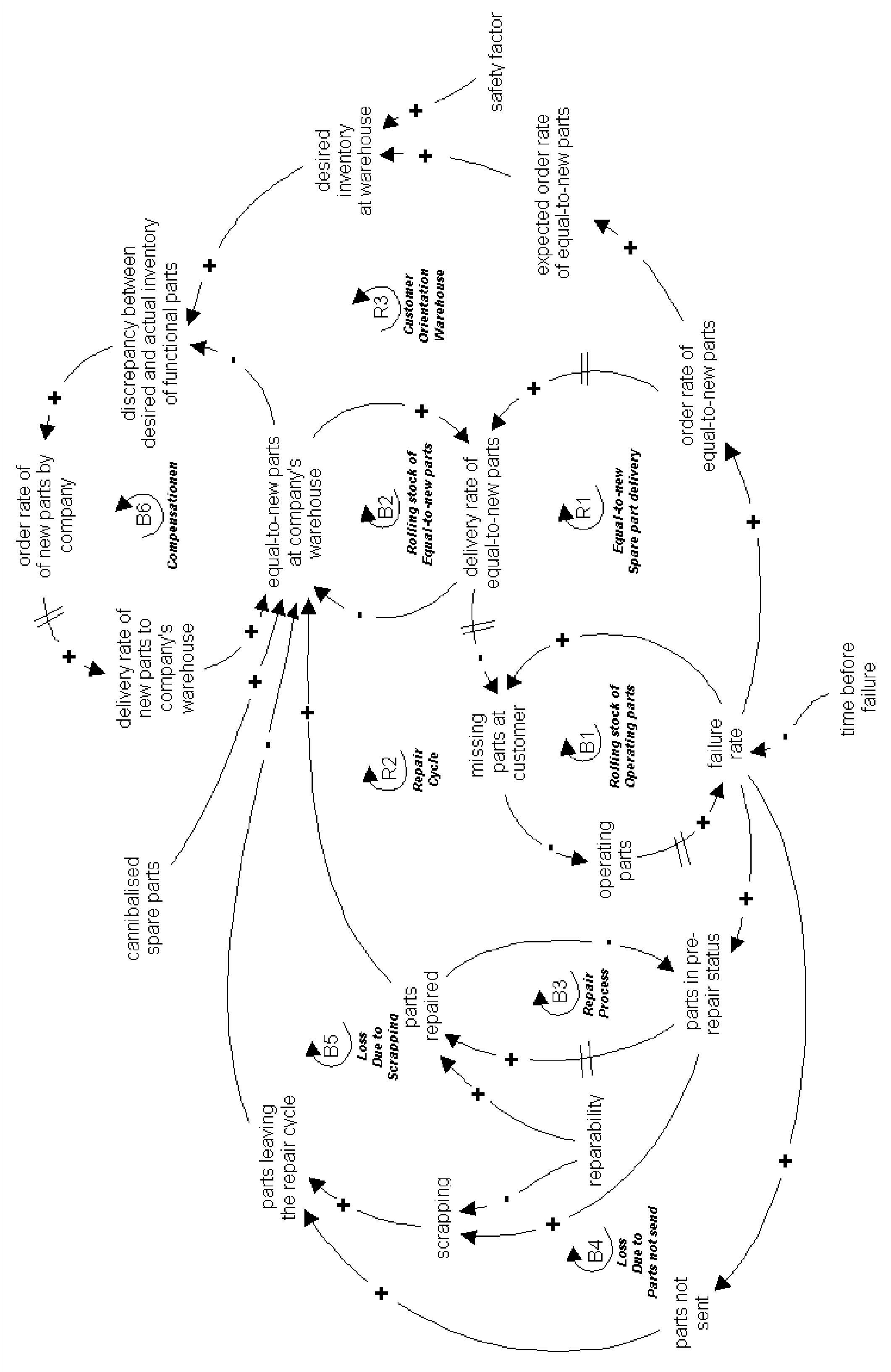

Figure 3: Repair cycle with compensation of losses

The warehouse of the company is refilled by repaired parts (Loop R2). The more parts fail, the more parts enter the repair cycle. Between failure and start of the repair process they are in a so-called pre-repair status. This includes the time until they are released for sending by the customer,[5] the time for transportation and the storage time of parts before they enter the repair process. The more parts are in the pre-repair status the more will be repaired after a certain time, reducing the number of parts in the pre-repair status (Loop B3). As soon as parts are repaired, they are sent to the warehouse where they are stored until ordered and sent to customers. There they are installed at the places of the missing parts and operate until they fail again (Loop B1).

The number of parts repaired does not just depend on the number of parts in pre-repair status. It also depends on the reparability. Some parts fail in a way that they are not repairable anymore. They have to be scrapped and leave the repair cycle so that fewer parts arrive at the warehouse (Loop B5). Moreover some parts do not even enter the repair cycle although they failed. This happens as some customers do not send the failed parts. They are throwing them away or just store them somewhere. These parts are also lost and, in consequence, reduce the number of parts arriving at the warehouse (Loop B4).

Yet, for those parts that were lost compensation has to be organised. One possibility is to cannibalise discarded machines. Those parts that are still useable and fulfil the required aspects of quality are sent to the company's warehouse. Another possibility is to order new parts which will be received after a certain time. The number of parts ordered depends on the discrepancy between desired and actual inventory of functional parts.[6] The desired inventory depends on the expected order rate (Loop R3), corrected by a certain safety factor. The higher the discrepancy the more parts are ordered and delivered after a certain time, increasing the number of parts in the RWH (Loop B6). New parts are ordered until the desired inventory is reached.

5. Conceptual Model

The stock and flow diagram contains four main sectors. The connection between them can be seen in Figure 4 (page 8). A black, bolded arrow indicates material flow, a black, dashed arrow information flow. Exogenous variables are indicated with a grey background.

The Customer Sector describes in what frequency failed parts are shipped to the Repair Sector and shows the delivery of equal-to-new parts from the Return Sector. Information about customer orders and order fulfilment are exchanged between Customer Sector and Return Sector. Parts that failed are sent to the Repair Sector. The sector includes internal and external repair and contains the decision rule about the location of repair. Those parts that are leaving the repair cycle, because of scrapping or not being sent, have to be replaced. The information about the necessity of replacement is processed in the RWH (Regional Warehouse) Replenishment Sector, from where

---

[5] Customers do not send the parts immediately after they fail. They wait until they receive the ordered parts and send them afterwards. This is an additional delay in the repair cycle.

[6] The ordering policy introduced here is a very simplified one. Yet, it is sufficient in this case. For an extended analyses of ordering policies and storage strategies with help of System Dynamics, please refer to Finkenwirth, A. (1993).

newly produced and/or cannibalised parts are delivered. In addition the model contains sub sectors where lead time, capital lockup, storage costs and transportation costs are calculated.

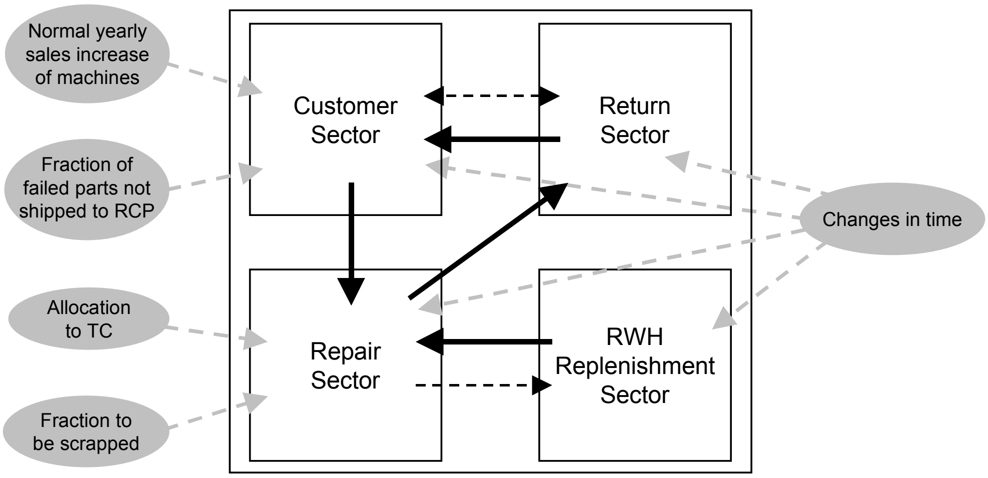

Figure 4: Conceptual Model

The model is based on the following assumptions:

• Parts are not perishable	Parts are made out of materials that are not perishable.
• Parts do not become obsolete	As the simulation is running over a relatively short time horizon, compared to the obsolescence of the machines, this is a sufficient condition.
• No lost demand	The demand is either satisfied immediately or, in case there are not enough inventories, as soon as there are new parts in the inventory. There is no demand lost to other competitors, as none of them can deliver spare parts for these machines.
• No additional orders	If demand cannot be satisfied immediately, customers do not place additional orders.
• Constant lifetime of machines.	The lifetime of the machines is assumed to be independent from their utilisation.
• Constant fraction of repairable parts for internal and external repair	Whether a part is repaired internally or externally just depends on technological aspects, not on capacity constraints.
• No capacity constraints in transportation.	As transportation is conducted by commercial parcel services, it is possible to hire as much transportation companies as necessary.
• No capacity constraints in storing.	As the company is having huge storage facilities, the model is running under the assumption of no capacity constraints. Yet, the author recommends comparing the results of the simulation with the actual storing capacity, specifically during the transient phase.

• Limited repair capacity.	The repair capacity (Maximum repair rate) cannot be expanded. Therefore it is seen as limited.
• Parts are divisible arbitrarily often.	This is a sufficient condition for a large number of parts, such as in this repair cycle.[7]

6. Behaviour Analyses

One objective of reducing the lead time of the repair cycle is, as mentioned before, the reduction of **capital lockup (CL).** When speaking about capital lockup in parts it is referred to parts that are not in operation in any of the machines. In other words, all non-productive parts are taken into consideration. The capital lockup is calculated in the model by referring to the number of parts in the repair cycle and the replacement costs of a part (2000 Euro/part).

On the other hand **storage costs (StoCo)** play a significant role. They are calculated for the company, only. In other words, storage costs at customers are not taken into consideration. The storage costs are calculated by referring to the number of parts in the considered station and the storage costs of a part (0.04 Euro/day).

Besides those "hard" factors, the effect on **customer satisfaction** is of high interest. It is assumed that the perceived degree of order fulfilment reflects the satisfaction of customers.

In a first step, single policies were defined and tested in order to analyse the effects on the above key variables separately. The following policies were analysed (see Figure 7 5):

1. reducing RWH replenishment time and its variance,
2. reducing shipment time from RWH to customers,
3. reducing shipment time and variance from customer to RCP and
4. reducing shipment time from RCP to ER and TC:

Shipment time and variance from customer to RCP were unacceptable, as well. By convincing the customer about the necessity to ship parts faster, an improvement could be achieved. The shipment time could be reduced from 25 days to 10 days, its variance from 5 days to 2 days.

Shipment time from RCP to ER and TC were as well seen as too long. By optimisation processes inside the RCP the shipment time could be reduced from 18 days to 3 days.

---

[7] see also Fauser, M. (1995, p. 15).

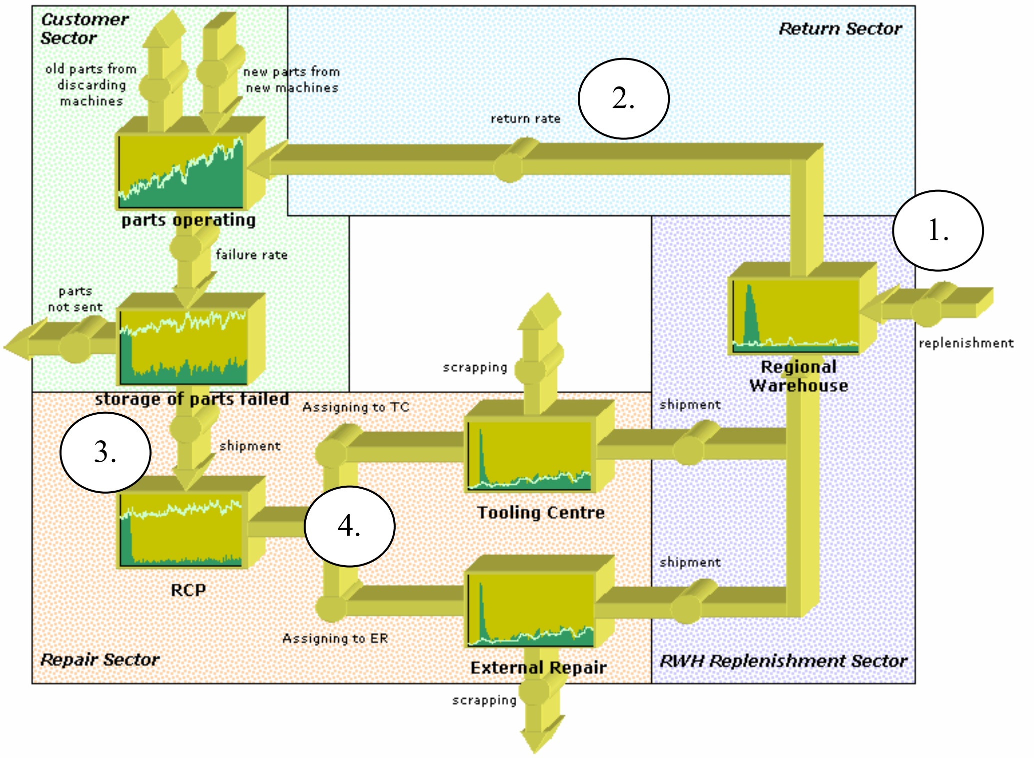

Figure 5: Implemented Policies

In this executive summary we will not discuss the resulting behaviour of every single policy. Rather, we hereby encourage the reader to play with the model himself.[8] The model runs over a time horizon of 3 years. The policies are activated after 100 days and can be tested separately or in combination. The focus in this paper is on explaining the behaviour that arises out of the combination of all four single policies. Figure 6 and Figure 7 represent the resulting behaviour.[9] Major outcomes were found on the one hand in respect to the transient behaviour of parts in the repair cycle, respectively capital lockup and storage costs, and on the other hand in respect to customer satisfaction:

All in all, the mean lead time was reduced from 73 days to 42 days (respectively from 76 to 45) for parts that are repaired at the Tooling Centre TC (respectively at External repair station ER). In addition the variance of the lead time decreases as well. The transient behaviour reflects a worse-before-better situation, concerning capital lockup and storage costs. After the changes in shipment time and variance are activated, both of them are at first increasing as the number of parts in the repair cycle increases. This is caused on the one hand by a faster shipment to the RWH (policies 3 and 4) and on the other hand by a "flood" of replenishment parts caused by the sudden decrease in replenishment time (policy 1). The previous long replenishment time delays were responsible for a plenty of open orders of replenishment parts. These open orders cannot be withdrawn and are suddenly "flooding" the RWH. In consequence, the RWH stops ordering replenishment parts until the sudden increase is balanced. Yet, as soon as the increase is balanced, capital lockup and storage costs decrease further, as the “faster

---

[8] As the file exceeds the maximum file size of 2 MB it can not be enclosed in the conference material. Yet, the author hereby offers to send the file to the interested reader upon request.

[9] Light green lines indicate the base run, bold green lines indicate the final behaviour.

repair cycle pays off in the need for fewer 'spare' parts."[10] In consequence, the capital lockup decreases by more than 20 Million Euro to about 30 Million Euro. Afterwards it is just increasing slightly because of additional parts in the repair cycle, originating from the increase in the number of sold machines. Storage costs first increase to more than 900 Euro/day, caused by the extreme growth of parts in the RWH, and decrease afterwards to less than 400 Euro/day.

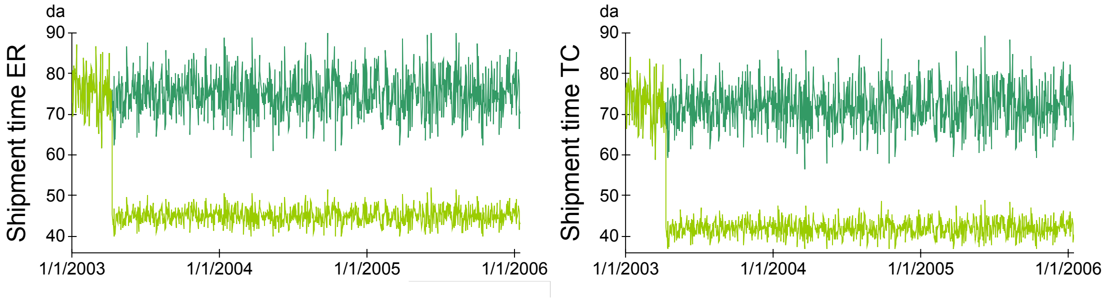

Figure 6: Combined policies – Sum of Shipment time along TC and ER

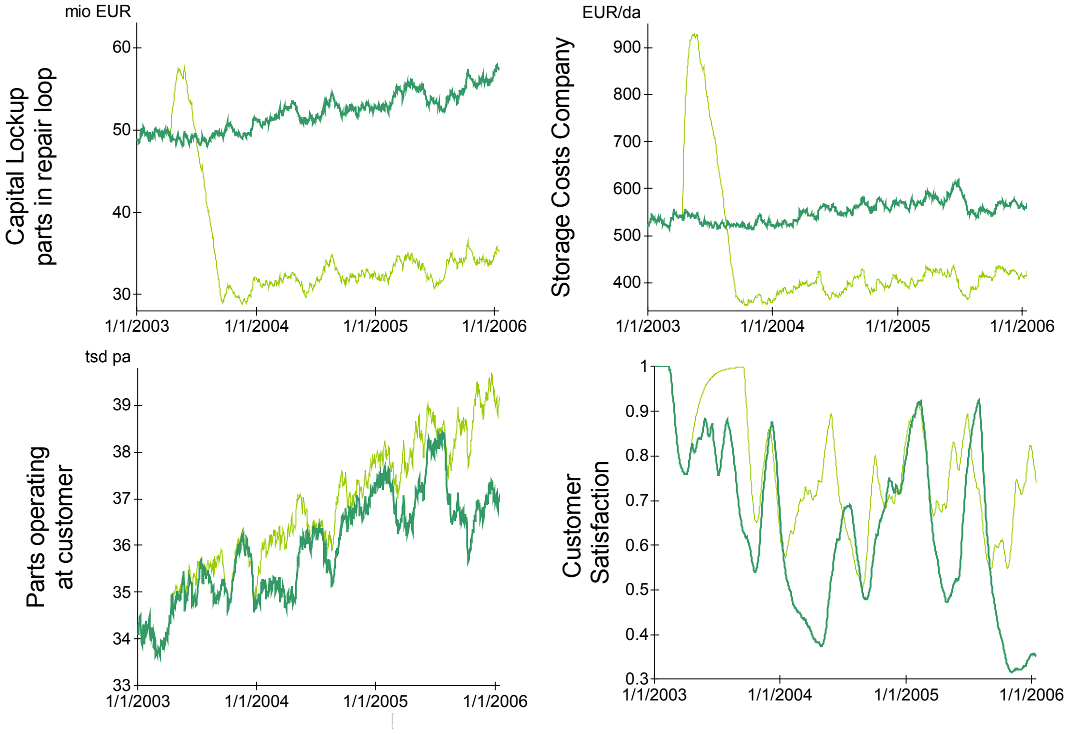

Figure 7: Combined policies – Behaviour of key variables

From the reduction in mean lead time it was expected that the customer satisfaction would increase significantly. Yet, in this case a counterintuitive behaviour could be observed. Although, customer satisfaction improves rapidly when just activating the single policy of decreasing the replenishment time (policy 1), the overall result does not show considerable improvements. The reason is: By reducing the shipment time from RWH to customers (policy 2) the ordering amount of the RWH is adjusted as well. The desired inventory is derived from the expected average orders and the shipment time to

---

[10] Patton Jr., J.D. (1984, p. 238).

customers, corrected by a certain safety factor. As the shipment time to customers decreases, the desired RWH inventory decreases as well, resulting in a lower number of parts stored in the RWH. Having fewer parts stored, the degree of order fulfilment deteriorates, as the flexibility to react to changes in customer demand decreases. Therefore, the customer satisfaction gets worse, compensating almost 100% of the increase in customer satisfaction caused by the decrease in replenishment time.

7. Prospective

For a further development of the model, an inclusion of preventive actions is suggested. This refers for example to taking into consideration the supply line, when ordering new parts, or conducting a preventive maintaining strategy on the customer's side. In addition, the structure of the main sectors of the model can be used as the basis for an elaboration on the environmental effects of repair cycles.

References

Davidsen, P.I./Ford, D.N./Mashayekhi, A. N. (2000): Sustainability in the Third Millennium - Proceedings of the 18th International Conference of the System Dynamics Society, Bergen 2000.
Fauser, M. (1995): Stochastische Lagerhaltungsmodelle mit Nachfrageinformation: Strukturuntersuchungen mit Methoden der Markovschen Entscheidungsprozesse, Diss., Karlsruhe 1995.
Finkenwirth, A. (1993): Ersatzteildisposition in der Automobilindustrie mit einem System-Dynamics-Lagerhaltungsmodell, Diss., Mannheim 1993.
Haasis, H.-D. (1999): Produktkreislauflogistik, in: Logistikforschung, Entwicklungszüge und Gestaltungsansätze, ed. by Pfohl, H.-C., Berlin 1999, pp. 253-277.
Hansen, U. (1999): Produktkreisläufe - Schlüssel zum nachhaltigen Wirtschaften, Stuttgart 1999.
Patton Jr., J.D. (1984): Service Parts Management, New York 1984.
Reith, R. (2001): Recyclieren und Reparieren in historischer Sicht. in: Ferrum, no. 73, 2001, pp. 25-31.
Schuppert, F. (1994): Strategische Optionen für Anbieter auf Ersatzteilmärkten, Wiesbaden 1994.

Back to the Top