From Waste to Value – A System Dynamics Model for Strategic Decision Making in Closed-Loop Supply Chains

Christian Lehr, Peter M. Milling

Industrieseminar, Mannheim University
Schloss, D-68131 Mannheim, Germany
phone: +49 621 181 1582
facsimile: +49 621 181 1579
clehr@is.bwl.uni-mannheim.de
pmilling@is.bwl.uni-mannheim.de

Abstract: *The purpose of this paper is to develop a system dynamics model which allows an Original Equipment Manufacturer in the electronics industry to test different value recovery strategies in a Closed-Loop Supply Chain setting. Due to shortening product lifecycles and legislative regulations, companies face the challenge of handling products at their end-of-use or end-of-life. Accordingly, effective strategies for the collection and value recovery of these products have to be developed. The model presented in this paper is the preliminary result of an ongoing research project. First simulation experiments conducted on the current model structure on the one hand show the economic potential of an engagement in value recovery activities and on the other hand highlight the high complexity and connectivity inherited with various value recovery processes.*

Keywords*:* *Closed-Loop Supply Chains; electronics industry, value recovery*

Introduction

High sales volumes and shortening product life cycles cause an increasing number of obsolete products in the market for electronics. In many industrialized countries legislation holds Original Equipment Manufacturers (OEM) responsible for these products and enforces them to bear any costs arising at the end of a product's life. This leads to various challenges OEMs have to face with regard to the lifecycle-management of their products. However, this situation also implies a large potential for any activity involved in the process of recovering value of end-of-use (EOU) or end-of-life (EOL) products (Guide 2003). In the past, management emphasis has solely been set on the early stages of a product's lifecycle, mainly pursuing the goal of a fast introduction to the market in order to generate high market shares and economies of scale. Activities concerning the return, recycling, or the disposal of a product were hardly taken into consideration (Thierry et al. 1995). Today, the attention is also shifting towards the phases at the end of a product's lifecycle (Marien 2006). EOU or EOL products are not regarded as a cost factor any more, but can rather be seen as an alternative to original resources which can be used for value-added activities (Dowlatshahi 2005). Accordingly, an increasing number of companies is now actively trying to manage product return flows and to develop strategies for efficiently designing product recovery activities (Toffel 2004; Kerr and Ryan 2001). In this context, the original supply chain needs to be expanded to a Closed-Loop Supply Chain (CLSC). The management of such a CLSC is defined as the "[…] design, control and operation of a system to maximize value creation over the entire life-cycle of a product with the dynamic recovery of value from different types of returns over time" (Guide and Van Wassenhove 2006, p. 249). The term *dynamic* in this definition implies that companies need to deal with numerous questions arising with regard to various activities like collection, inspection, remanufacturing, or materials recycling.

Particlularly remanufacturing processes and the distribution of remanufactured products on a secondary market – this market can differ from the primary market either by the targeted customer segment or by georaphic region – increasingly proves to be a profitable field of action for OEMs (Ferrer et al. 2006). However, a major prerequisitie for value recovery activities to be profitable is the ability of the OEM to reduce the uncertainty involved with the quantity, quality and timing of product returns (Inderfurth 2005). The high degree of uncertainty in the context of CLSCs leads to a strong increase of complexity in comparison to traditional supply chains. In order to countervail this complexity, there is a need for suitable instruments to support OEMs in their strategic decision making when trying to manage CLSCs. This paper contributes to an improvement of strategic decision making in CLSCs by offering a generic simulation model which can be used to test various strategic product recovery policies in different settings of the competitive environment.

Among possible questions to be answered by the model are the following. First and foremost it has to be looked at the question whether it is at all profitable for an OEM to actively engage in recovery activities, or whether it is better to ignore obsolete products and to regard possible costs of disposal as sunk costs. It is proposed that the answer to this question highly depends on certain environmental settings like legislation, raw material prices, or attractiveness of the secondary market. In an ideal case, there will be a win-win-win situation, in which the customer profits from low prices for remanufactured products, the ecological environment is conserved from exploitation of resources, and the OEM is able to make economic profits from recovery activities and to establish an image as an environmentally friendly company (Seitz 2004). Besides the fundamental question stated above, there are a number of further questions regarding the detailed organization of collection and value recovery activities. Within this *process-oriented context*, the advantegeousness of various strategic options under differing circumstances has to be examined. Among those options are for instance different types of return policies the OEM might use to collect products and to reduce the uncertainty entailed with these products. These options can range from rebates to leasing contracts or buy-back programs, among others. Moreover, decisions on the appropriate collection, inspection and remanufacturing capacities have to be made. Furthermore, strategic decision making in CLSCs also has to be seen in a *product-oriented context*. One issue affected in this context is the decision on the types of products which might be included in value-recovery activities (e.g. B2B-products only, or also B2C-products?). Another issue is concerned with the design and construction of products, i.e. OEMs need to balance out how much should be invested in an easy-to-disassemble design in the construction phase of a product in order to save costs and time in later phases, when the product is disassembled and remanufactured (Johnson and Wang 1995).

The model presented in this paper is intended to give answers on the above outlined questions. Insights on the advantegeousness of certain *process*- and *product-oriented* options and their long-term consequences on various performance measures under different environmental circumstances should be provided. The current model structure presented in this paper incorporates the preliminary results of an ongoing research project. The next section of this paper motivates the use of System Dynamics as an appropriate method for supporting strategic decision making in CLSCs and gives a brief overview of so far existing System Dynamics applications within this field of research. Thereafter, the structure of the current model is introduced, first simulation runs are discussed and an outlook for the research to be conducted is given.

Literature Review

In the field of Supply Chain Management, System Dynamics has been applied from the very beginning, as Forrester’s early publications show (Forrester 1958, 1961). The method has proven to be a powerful tool for developing a general understanding for the underlying problem structures within Supply Chains, which often cause large bullwhip effects and therewith a poor overall performance of the Supply Chain. However, the application of System Dynamics in Supply Chain Management has almost solely been limited to the modeling of forward material flows. Due to the increased complexity in CLSCs, particularly caused by the high degrees of uncertainty and the high number of actors involved (Guide and Jayaraman 2000), System Dynamics can also be seen as an adequate method to model problems related to CLSCs. In the following, a brief overview of the so far existing applications of System Dynamics in the context of CLSCs will be given.

Triggered by legal regulations concerning the recycling and disposal of old cars in Europe and the U.S, the focus of the first models during the 1990s is directed towards problems in the conetxt of automobile recycling. Zamudio-Ramirez (1996) models substantial interactions between car manufacturers, consumers and recycling companies in the United States. He analyzes the effects of legal and technological changes on the whole industry. Seebach (1996) particularly investigates the costs of car recycling in Germany and analyzes the effects of different environmental instruments on cost development. He is able to show the long-term consequences of policies promoted by the legislative body in comparison to policies favoured by car manufacturers. Another monograph in the field of CLSCs and System Dynamics was published by Schröter (2006). He emphasizes on spare part management in CLSCs in the electronics industry. His model serves as a decision support system for spare part supply after volume production and has to be seen against the background of an OEMs long term commitment to provide spare parts. Alternative scenarios and strategies for the application of product components are analyzed.

Apart from the above presented monographs there are also a number of journal articals on System Dynamics approaches to CLSC problems. Georgiadis and Vlachos (2004) examine the effect of environmental issues on the long-term decision making with regard to collection and remanufacturing activities as well as the impact of these environmental issues on changes in customer demand. Their interest is particularly directed towards a company's green image effect on customer demand and towards the general consequences of take back obligations imposed by legislation. Another important aspect when managing product return processes can be seen in the challenge of capacity planning. This issue is considered by Georgiadis et al. (2006). They analyze how lifecycles and return patterns of various products affect the optimal policies regarding the expansion and contraction of collection and remanufacturing capacities. Kumar and Yamaoka (2007) use System Dynamics to explore the relationships between reduce, reuse, recycle and disposal activities in the Japanese car industry. They analyze different market scenarios and show how various logistics elements will be affected by government regulations on a long-term basis.

Model Structure

The model developed in this paper represents a decision framework for an OEM in the electronics industry. The OEM is already active in producing and selling high-value goods on a primary market. Due to legislative pressure on the one hand, and an increasing customer awareness towards a higher environmental consciousness on the other hand (Gungor and Gupta 1999), the OEM is forced to deal with the question on how to react to such developments and whether it is reasonable to engange in value recovery activities. Accordingly, "the most fundamental question is whether producing a remanufacturable product is profitable" (Debo et al. 2005, p.1194). The model should provide an answer to this question and should offer further implications on which strategies of value recovery should be followed under different circumstances.

Within this research setting, it can be looked at four general strategic options of the OEM. The first option implies that there will be no engagement in any value recovery avtivities and that the attention of the company is kept solely on the primary market. The second option involves collecting old products, remanufacturing these products, and selling them on a secondary market. A third strategic option would imply the collection of old products but no remanufacturing activities. Instead, the old products would be recycled on a raw materials basis. Raw materials can be fed into the original manufacturing process of the primary product. The fourth option denotes the highest degree of value recovery. It involves remanufacturing and selling remanufactured products on a secondary market as well as recycling old products that are not suited for remanufacturing and feeding recycled raw materials into the original production process. All of these options can be implemented in the System Dynamics model and the respective long-term implications under various environmental scenarios can be tested. Figure 1 gives an overview of the model structure. The respective model sectors will be explained in more detail in the following.

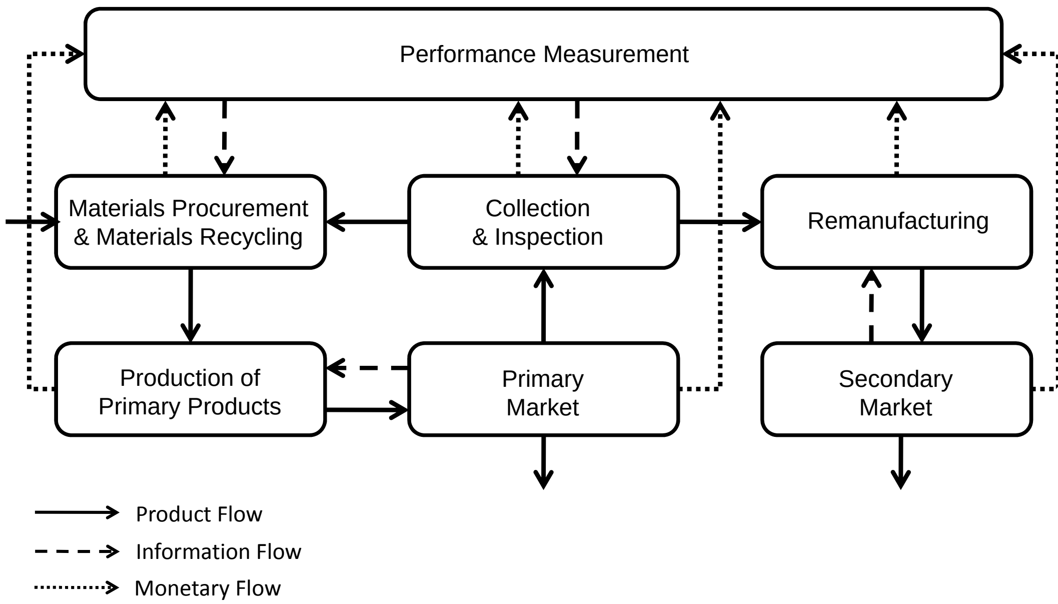

Figure 1: Overview of model structure with respective connections between model sectors

The OEM produces high-value products and sells these products on a **primary market**. The primary market sector is modeled by using a four-stage aging chain (Sterman 2000). This allows for testing different return policies by varying return rates from the respective cohorts in the aging chain. If the OEM chooses not to engage in any return and recovery activity, all products leave the primary market at the end of their regular lifetime and are disposed of. In this case, the OEM is imposed by legislation to bear all costs involved with the disposal of the products. If management decides to engage in product recovery, products from the primary market are not disposed, but enter the model sector collection and inspection.

The sector **collection and inspection** is influenced by a number of different drivers. The collection rate depends on the effort and the incentives the OEM provides to his customers for returnig obsolete products. The OEM tries to adjust the number of returned products to the number needed for remanufacturing or recycling. Since products in the electronics industry can be characterized as very time-sensitive – the average value loss of these products amounts for about 1% per week (Blackburn et al. 2004) – a major goal of the OEM should be to establish a low and fairly stable inventory of returned products in order to avoid high value losses. Accordingly, the storage time of returned products serves as an important controlling parameter for decision makers to put more or less effort and incentives into product collection. The functional relation between storage time of collected products and the pressure to change return rates is illustrated in figure 2. In an equilibrium situation the perceived storage time of returned products matches the desired storage time, which has the effect that the desired return rate is constant. A perceived storage time that is shorter than the desired storage time implies that there are not enough old products on stock. This leads to an increase of the desired product return rate. The opposite effect results in a situation in which a large stock of returned products has been accumulated.

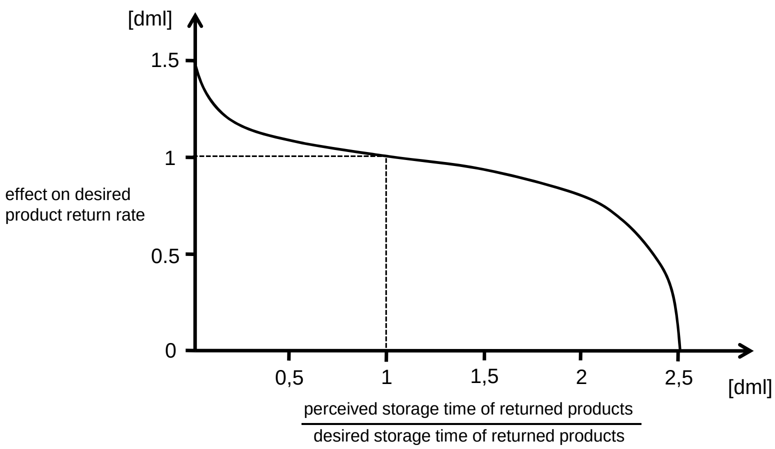

Figure 2: Effect of storage time of returned products on desired return rate

After being collected, normally all products are inspected and sorted into two categories: high and low quality. High quality products can be used for remanufacturing, low quality products can only be used for raw materials recycling. In the model, the quality of the returned products solely depends on product age. The relationship between the residual value of a product and its suitability for remanufacturing is depicted in figure 3.

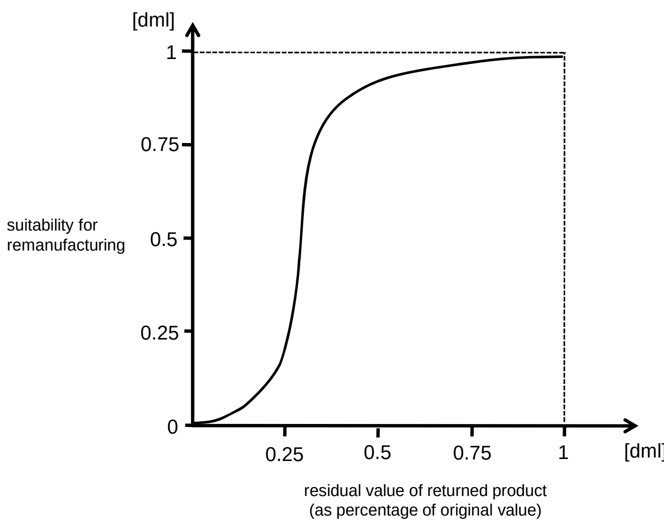

Figure 3: Relation between residual product value and suitability for remanufacturing

Products which are sorted into the high quality category subsequently flow into the **remanufacturing sector** of the model. The structure of this sector can be described as a pull-system. Depending on the demand for remanufactured products on the **secondary market**, products are pulled out of the stock of remanufacturable products and are fed into the remanufacturing process. Investments done by the OEM towards a higher degree of design for disassembly result in a shortened remanufacturing cycle time. This leads to better responses to customer demand on the secondary market and to general savings in the remanufacturing process. If demand on the secondary market cannot be satisfied, the pressure to increase product return ratios, respectively the fraction of old products suitable for remanufacturing, will rise in the long run.

Lower quality products, which cannot be used for remanufacturing, are led into the model sector **materials procurement & materials recycling**. In this sector, management makes decisions on whether to procure raw materials from external suppliers or whether to recycle old products in order to provide raw materials for the manufacturing process of primary products. The model structure which incorporates this decision process is illustrated in figure 4.

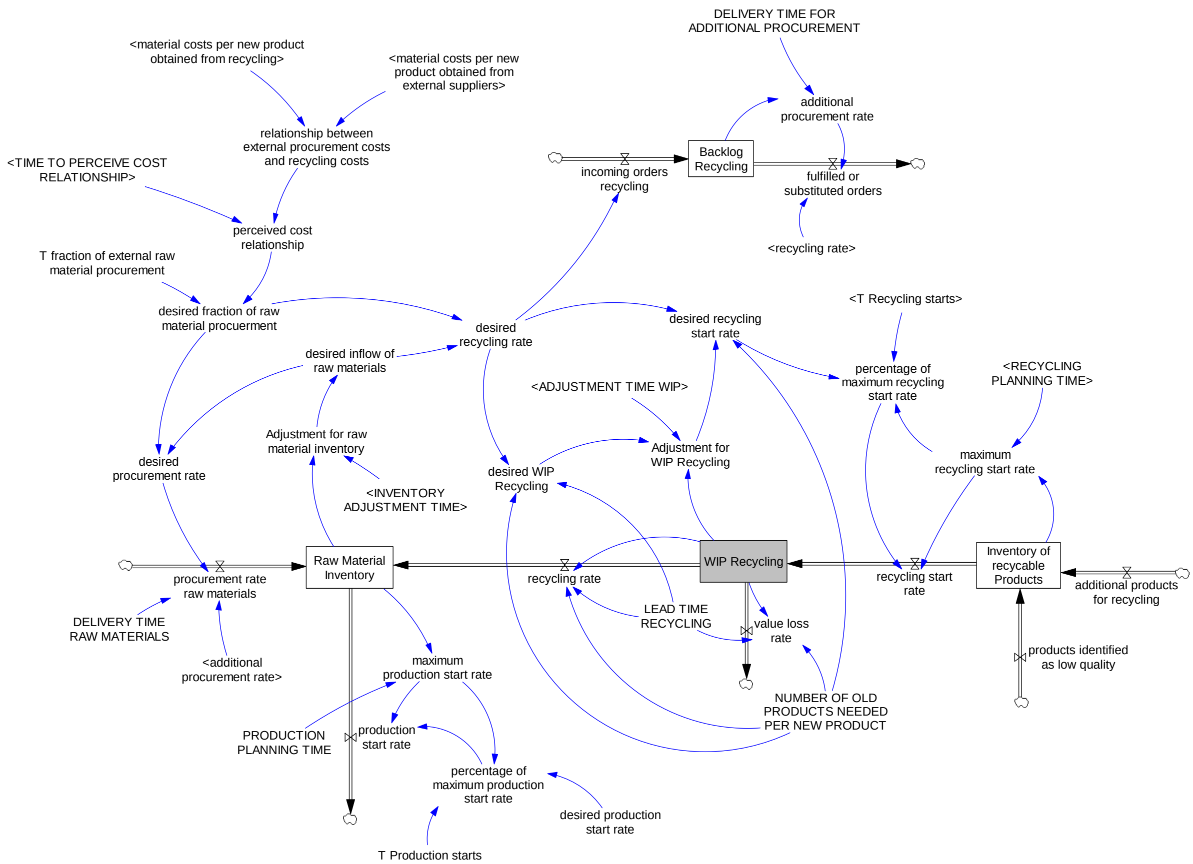

Figure 4: Structure of the model sector "materials procurement & materials recycling"

Decision makers compare the market price for raw materials needed for one new product with the costs for recycling in order to obtain the same quantity of raw materials.

Depending on which option is cheaper, the respective fraction of external procurement or internal recycling is chosen. Normally, there will be a mixture of procurement and recycling. A scenario, in which there will be no external procurement at all is not allowed for in the model, since the quantity of materials gained through recycling will ususally not be sufficient in order to produce the total amount of new products needed on the primary market (Ferrer 1997). However, in a scenario in which raw material prices are very high in comparison to an obtainment of these materials through recycling, the OEM will try to exhaust the recycling option as much as possible. In such a situation, it is possible that an overstock in the inventory of collected products can be fed into the raw materials recycling process without running through inspection. These products are represented by the rate "additional products for recycling" in figure 4. The fraction of raw materials needed, which cannot be acquired through recycling, will always be bought from external suppliers, regardless of the price.

The material flow from the above described model sector into the sector **production of primary products** is also modeled as a pull-system: demand on the primary market triggers manufacturing processes in the production sector which in consequence leads to a desired inflow into the stock 'raw material inventory'. Whether this inflow is obtained through external procurement or recycling depends on the incorporated decision process described above.

All processes and activities executed by the OEM are assessed in the sector **performance measurement**. Monetary flows feeding this sector include revenues from the primary as well as from the secondary market. Moreover, the following costs are included: manufacturing costs for the production of primary products (including labour costs and costs for materials – either procured externally or obtained from recycling), collection costs (including return incentives), inspection costs, inventory costs as well as remanufacturing costs for secondary products. Moreover, in case the OEM is not engaged in any recovery activities, costs for the disposal of obsolete products are also contemplated. All in all, this sector on the one hand helps to assess the profitability of all processes and activities, and on the other hand, depending on these profitability measures, it also serves as an information and regulation tool for decisions to be taken in forthcoming periods. Hence, performance measurement particularly influences management decisions on collection activities as well as recycling and procurement activities.

Preliminary Simulation Results and Outlook

In the following, first simulation results carried out on the current model structure will be presented, and an outlook on upcoming steps to be conducted within this research project will be given. First of all, an equilibrium scenario is presented in order to give an overview of certain assumptions with regard to the initial situation on the primary and on the secondary market. In this scenario, two policies for an OEM are compared: on the one hand the option of not doing any value recovery and focussing on selling primary products, and, on the other hand, the option of doing the highest degree of value recovery possible. This second policy implies active collection of old products (including providing customer incentives for returned products), remanufacturing products for the secondary market, and recycling products in order to obtain raw materials for manufacturing primary products.

As can be seen in figure 5, the demand on the primary market is 125 products per week, whereas the demand on the secondary market is 50 remanufactured products per week. It is assumed that by different means of product acquisition management (Guide and Van Wassenhove 2003), it is possible for the OEM to actively collect 80% of the products sold on the primary market. It is also argued that by providing incentives to the csutomers, the OEM is able to control the quantity and timing of returned products. Each week 100 collected products are fed into the inspection and sorting process. This leads to a stable inventory of collected products. In the equilibrium situation, half of the products returned pass the inspection and can be used for remanufacturing, whereas the other half is fed into the recycling process. Hence, the procurement rate of new materials is lower for the value recovery option. Depending on raw material prices, this can save costs in the manufacturing process of primary products.

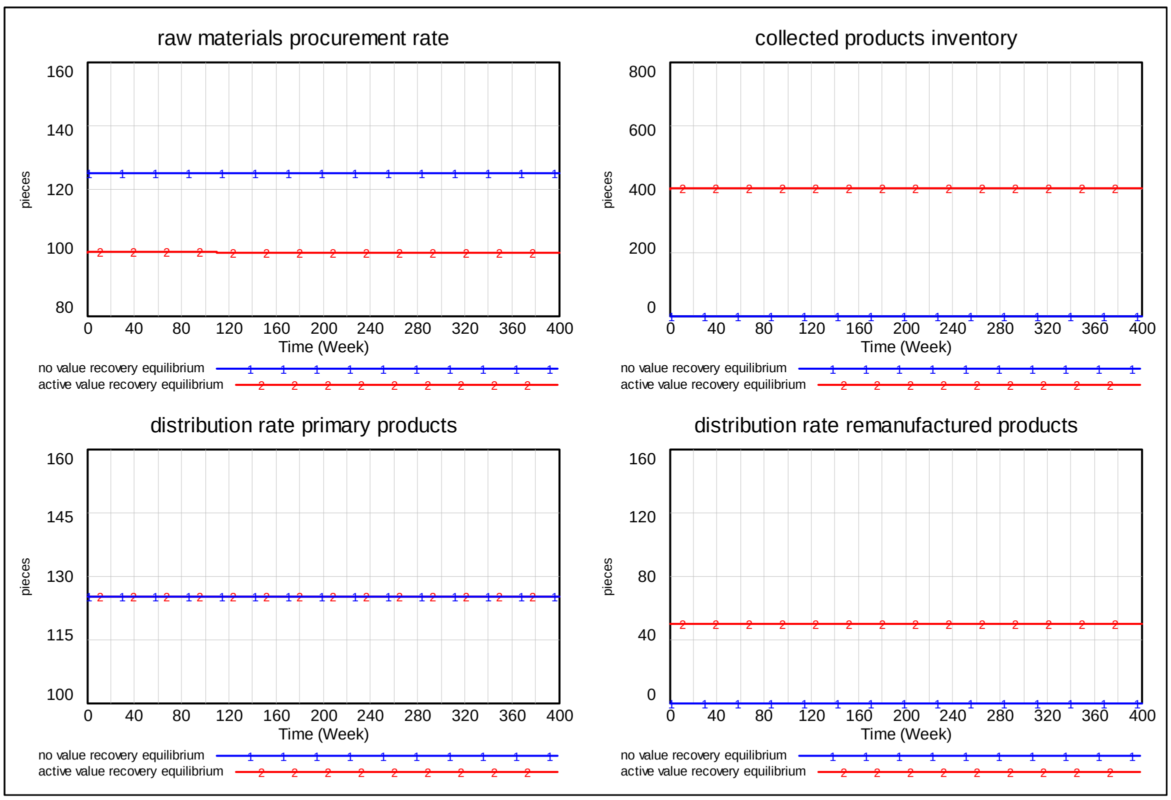

Figure 5:Equilibrium runs for no value recovery and active value recovery policies

As mentioned in the description of the model structure, a performance measurement sector has been established in order to assess each policy simulated. At this point, information from companies' websites as well as from the Literature – in particular from case studies – has been used to calibrate this model sector with regard to different costs and revenues (Spengler and Stölting 2008; Guide et al. 2005). Figure 6 compares the profits cumulated over the entire simulation time for the two policies “no value recovery” and “active value recovery”. It can be observed that in an equilibrium situation, characterized through stable demand on primary and secondary market, stable prices, and controllable return rates, it is of advantage for an OEM to engage in value recovery. However, it has to be noted that no initial investments for the development of the necessary structures and capacities are considered in the model so far. It is planned to include such investments in the further modeling process.

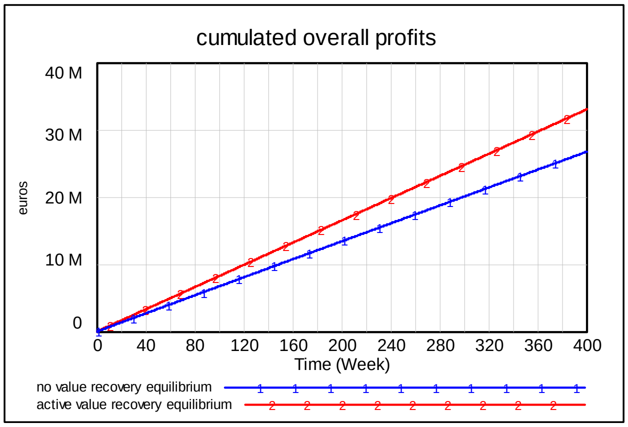

Figure 6: Cumulated profits with and without value recovery

The purpose of the upcoming simulation experiments is to highlight the interdependencies between the various model sectors and the effects of external shocks. In these experiments, the only policy considered is “active value recovery”, since this option affects all model sectors. The equilibrium scenario with a secondary market demand of 50 remanufactured products per week is now supplemented by a scenario in which there is a sudden increase in demand on the secondary market by 20%, as well as a scenario in which there is a decrease in secondary demand by 20%. Figure 7 depicts the simulation results caused by these external shocks.

A positive demand shock on the secondary market implies an immediate increase of inspection and sorting activities. This rapid adjustment leads to a decrease of collected products inventory and therewith to a decrease in the perceived average storing time of collected products (from an initial storage time of four weeks down to a value of about one week). This shortened storage time on the one hand implies a higher average residual value of the products collected, which in turn leads to an increased ratio of remanufacturable products. However, the 20% higher demand for remanufactured products cannot be satisfied by simply reducing the storage time of collected products and therewith increasing their suitability for remanufacturing. Far more important is an increase of collection rates in order to satisfy the higher demand on the secondary market. Therefore, shortening storage times of collected products also increase pressure on management to put more effort in collecting old products from the primary market. To do so, existing collection activities have to be adjusted or new collection programs (e.g. buy-backs programs, return incentives, leasing programs) have to be implemented. The time delay needed for the implementation of such changes is responsible for the overshooting behavior of the collected products inventory.

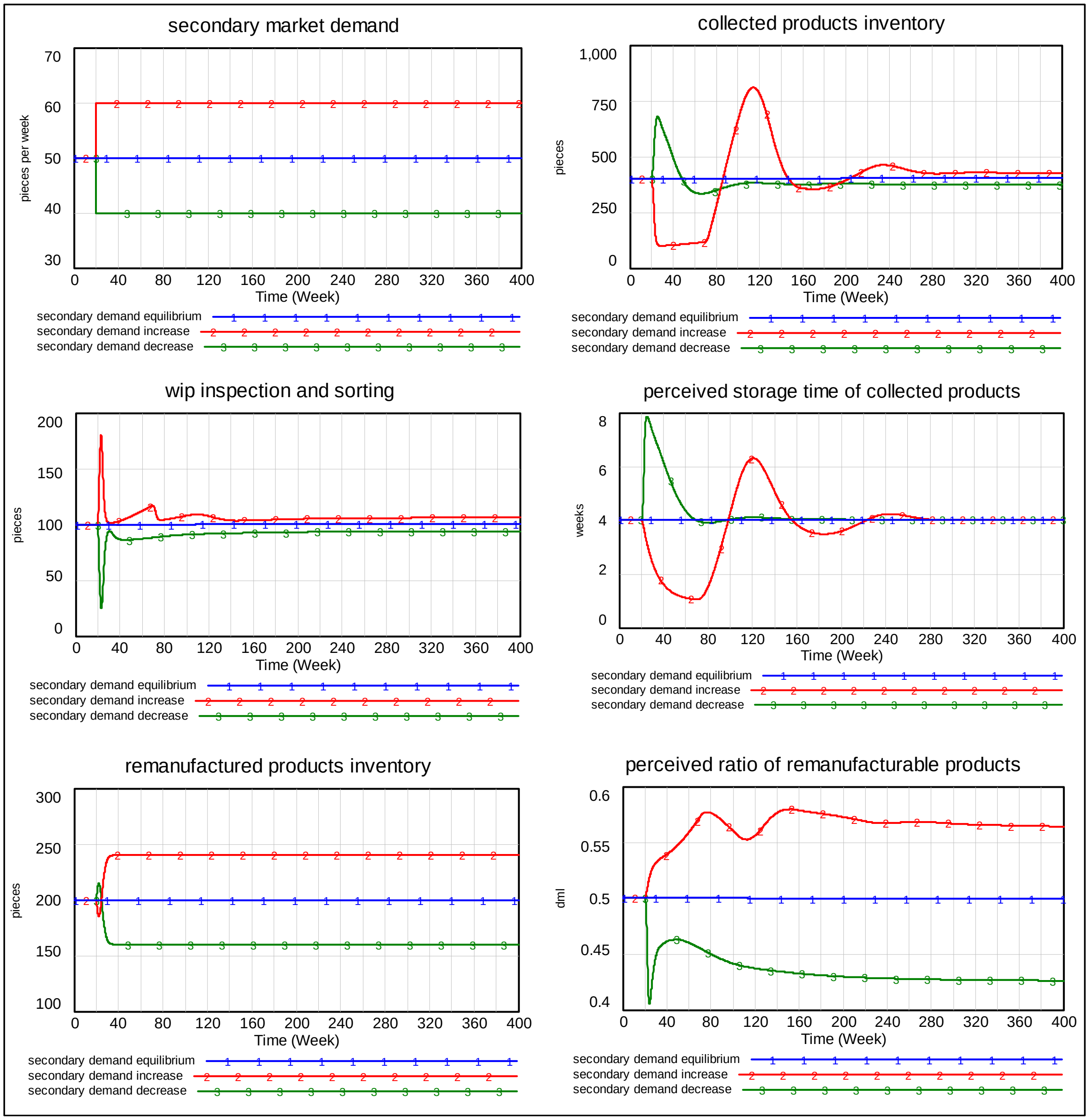

Figure 7: Effect of secondary demand increase and decrease on different variables

The major feedback loops responsible for the above described behavior are summarized in figure 8. An increase in the demand for remanufactured products creates pressure to collect more old products until the demand on the secondary market can be satisfied (*value recovery loop*). Besides this balancing loop, there is a second balancing loop which also affects the pressure to adjust the collection of old products. This loop is controlled by the desired storage time of collected products. The more products there are on inventory, the longer the storage time, the smaller the intended collection ratio (*adjustment* *of collection ratio loop*). Moreover, there is a reinforcing loop regarding the residual value of collected products and therewith their suitability for remanufacturing: the longer the storage time, the smaller the residual product value, the smaller the ratio of remanufacturable products. A smaller ratio of remanufacturable products in turn leads to a desired increase of product collection activities (*remanufacturability loop*).

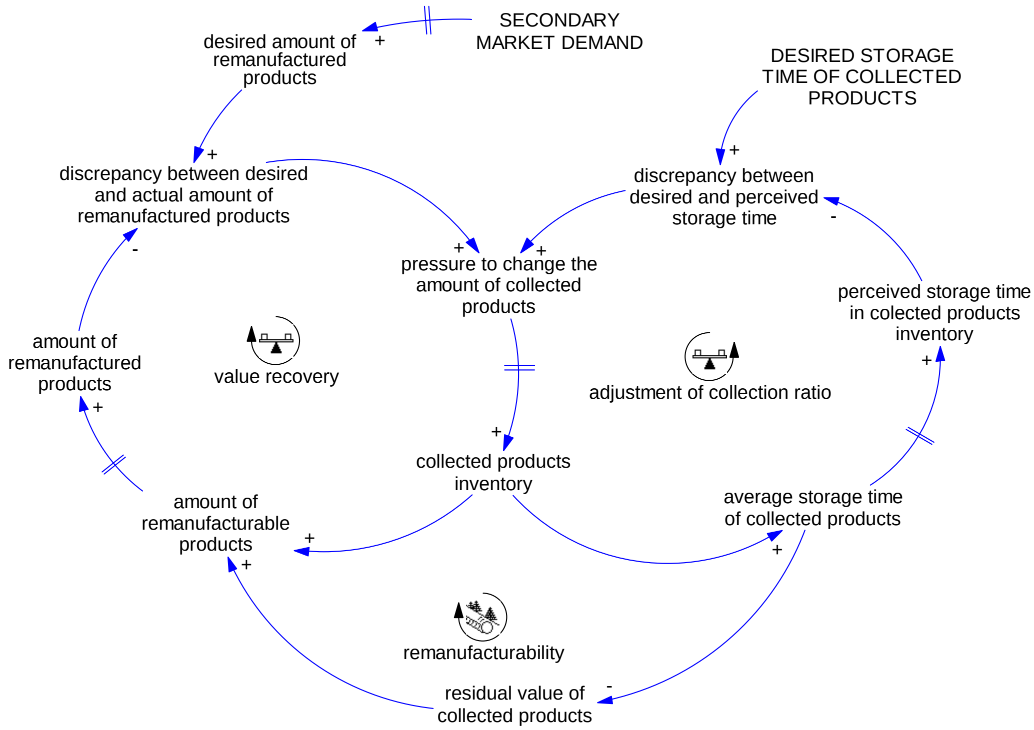

Figure 8: Causal loop diagram for collection and remanufacturing activities

An interesting fact which can be observed when looking at the scenario of a sudden demand decrease is that the inventory of collected products better adjusts to a negative demand shock. An overshooting behaviour like in the case of a positive shock can hardly be noted, and a stable inventory of collected products and therewith of the storage time is reached twice as fast. This behaviour can be explained by considering the recycling activities done by the OEM. As mentioned in the description of the model structure, the OEM has the opportunity to feed old products into the raw materials recycling process without doing any inspection and sorting activities. This is particularly the case when the inventory of collected products accumulates rapidly, as in the situation of a negative secondary demand shock. These additional recycling activities lead to a faster adjustment of the collected products inventory. Figure 9 tries to clarify this behaviour by showing the recycled products per week. The negative demand shock in period 20 leads to a temporary decrease in recycling activitites, caused by the lower WIP of inspection and sorting. However, shortly after, the higher inventory of collected products provokes additional recycling activities for the obtainment of raw materials. As a consequence, the inventory of collected products reaches a stable state much faster than in the case of a demand increase.

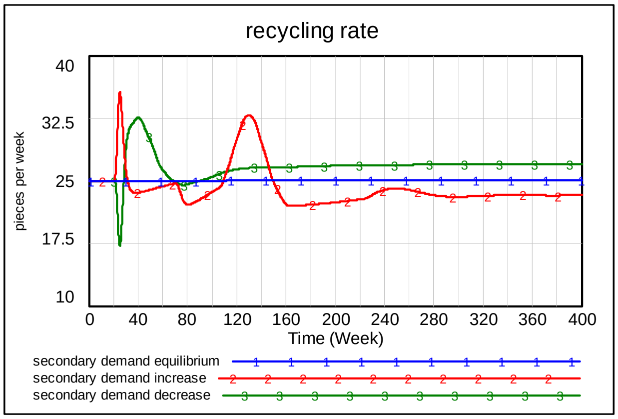

Figure 9: Effect of secondary demand shocks on recycling activities

The preliminary simulation results highlight the complexity inherent to decision making processes in CLSCs. Especially when implementing a policy which is aiming at high collection ratios and various value recovery activities – for instance remanufacturing products for a secondary market and concurrently recycling raw materials – many interdependencies have to be taken into account. An exogenous shock like a positive or negative shift in demand can have significant and long lasting influences on all proceses in this system, from procurement and production to collection and actual value recovery. The model can support corporate decision makers in getting aware of these interdependencies and on understanding long term consequences of particular recovery policies in different environmental settings.

To enhance the applicability of the current system dynamics model as an instrument for strategic decision making in CLSCs, some further aspects are intended to be implemented into the model in the next steps of this research project. An important aspect that will be considered is the relevance of capacity acquisition and capacity utilization with regard to inspection, remanufacturing, and recycling activities. It is expected that a consideration of capacity acquisition investments might lead to a worse-before-better-effect in the evalution of the overall profitability of value recovery activities. Another aspect that will be implemented applies to the evaluation of certain policies. So far, only monetary aspects are considered in the performance measurement sector of the model. However, it is argued that the active engagement of an OEM in product recovery also affects its image as an environmentally friendly manufacturer (Gungor and Gupta 1999). This will be taken into account in the further modeling process by including a “green image” variable in the performance measurement sector.

Furthermore, it is planned to apply the model in a case study with an OEM in the electronics industry. Conducting interviews with managers that deal with value recovery questions will also help in further validating the model. The final outcome of this research project should be a management cockpit which can be used by decision makers dealing with strategic questions in CLSCs. Different policies with varying degrees of value recovery can then be tested in different settings. These settings for instance might be characterized along the dimensions *sales potential on secondary market*, *raw material prices*, and *uncertainties inherited with product returns*.

References

Blackburn, Joseph D., V. Daniel R. Guide, Gilvan C. Souza and Luk N. Van Wassenhove. (2004). Reverse Supply Chains for Commercial Returns, *California Management Review*, 46 (2), pp. 6–22.

Debo, Laurens G., L. Beril Toktay and Luk N. Van Wassenhove. (2005). Market Segmentation and Product Technology Selection for Remanufacturable Products, *Management Science*, 51. (8), pp. 1193–1205.

Dowlatshahi, Shad. (2005). A Strategic Framework for the Design and Implementation of Remanufacturing Operations in Reverse Logistics, *International Journal of Production Research*, 43 (16), pp. 3455–3480.

Ferrer, Geraldo. (1997). The Economics of Personal Computer Remanufacturing, Resources Conservation and Recycling, 21 (2), pp. 79–108.

Ferrer, Geraldo and Jayashankar M. Swaminathan. (2006). Managing New and Remanufactured Products, *Management Science*, 51 (1), pp. 15–26.

Forrester, Jay W. (1958). Industrial Dynamics – A Major Breakthrough for Decision Makers. *Harvard Business Review*, 36 (4), pp.37–66.

Forrester, Jay W. (1961). Industrial Dynamics, Cambridge 1961.

Georgiadis, Patroklos and Dimtiros Vlachos. (2004). The Effect of Environmental Parameters on Product Recovery, *European Journal of Operational Research*, 157, pp. 449–464.

Georgiadis, Patroklos, Dmitrios Vlachos and George Tagaras. (2006). The Impact of Product Lifecycle on Capacity Planning of Closed-Loop Supply Chains with Remanufacturing, *Production and Operations Management*, 15 (4), pp. 514–527.

Guide, Daniel R. and Vaidyanathan Jayaraman. (2000). Product Acquisition Management: Current Industry Practice and a Proposed Framework, *International Journal of Production Research*, 38 (16), pp. 3779–3800.

Guide, Daniel R. and Luk N. Van Wasenhove. (2003). Managing Product Returns for Remanufacturing, in: Guide, Daniel R. und Luk N. Van Wasenhove (Eds.): *Business Aspects of Closed-Loop Supply Chains: Exploring the Issues*, Pittsburgh, pp. 355–379.

Guide, Daniel R., Luc Muyldermans and Luk N. Van Wassenhove. (2005). Hewlett-Packard Company Unlocks the Value Potential from Time-Sensitive Returns, Interfaces, 35 (4), pp. 281–293.

Guide, Daniel R. and Luk N. Van Wasenhove. (2006). Closed-Loop Supply Chains – An Introduction to the Feature Issue, *Production and Operations Management*, 15 (3), pp. 345–350.

Gungor, Askiner and Surendra M. Gupta. (1999). Issues in Environmentally Conscious Manufacturing and Product Recovery: A Survey, *Computers & Industrial Engineering,* 36, pp. 811–853.

Inderfurth, Karl. (2005). Impact of Uncertainties on Recovery Behavior in a Remanufacturing Environment - A Numerical Anaysis, *International Journal of Physical Distribution & Logistics Management*, 35 (5), pp. 318–336.

Johnson, M.R. and M. H. Wang. (1995). Planning Product Disassembly for Material Recovery Opportunities, *International Journal of Production Research*, 33 (11), pp. 3119 – 3142.

Kerr, Wendy and Chris Ryan. (2001). Eco-Efficiency Gains from Remanufacturing – A Case Study of Photocopier Remanufacturing at Fuji Xerox Australia, *Journal of Cleaner Production*, 9 (1), pp. 75–81.

Kumar, Sameer and Teruyuki Yamaoka. (2007). System Dynamics Study of the Japanese Automotive Industry Closed Loop Supply Chain, Journal *of Manufacturing Technology Management*, 18 (2), pp. 115–138.

Marien, Edward J. (2006). Meeting the Product Lifecycle Challenge, *Supply Chain Management Review*, 10 (7), pp. 50–56.

Schröter, Marcus. (2006). Strategisches Ersatzteilmanagement in Closed-Loop Supply Chains, Wiesbaden.

Seebach, Andreas. (1996). Betriebswirtschaftliche Systemanalyse des Fahrzeug-Recyclings in der Bundesrepublik Deutschland, Frankfurt am Main.

Seitz, Margarete A. and Ken Peattie. (2004). Meeting the Closed-Loop Challenge: The Case of Remanufacturing, *California Management Review*, 46 (2), pp. 74–89.

Spengler, Thomas and Wiebke Stölting. (2008). Life Cycle Costing for Strategic Evaluation of Remanufacturing Systems, *Progress in Industrial Ecology – An International Journal*, 5 (1-2), pp. 65–81.

Sterman, John D. (2000). *Business Dynamics – Systems Thinking and Modelling for a Complex World*, Boston.

Thierry, Martijn, Marc Solomon, Jo Van Nunen and Luk N. Van Wassenhove. (1995). Strategic Issues in Product Recovery Management, *California Management Review*, 37 (2), pp. 114–135.

Toffel, Michael W. (2004). Strategic Management of Product Recovery, *California Management Review*, 46 (2), pp. 120–141.

Zamudio-Ramirez, Pavel. (1996). Economics of Automobile Recycling, Cambridge.