EFFECTIVE USE OF RESOURCES IN CLOSED VALUE NETWORKS

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ABSTRACT

Currently, almost 60 billion tons of commodities are consumed worldwide each year. The effective use of resources is, therefore, an important key factor for sustainable development. Integrating recovered material at the end of the product's utilization phase into an existing production network can make a significant contribution to the effective use of resources. This paper proposes a methodology to manage inventory levels in order to enable the direct reuse of products considering reverse material flows in the calculations.

Keywords: closed value networks, effective use of resources, reverse material flows

1. INTRODUCTION

Raw materials and disposal capacities are resources that are not infinitely available. The limit to the availability of raw materials also imposes a limit to growth because entire industries depend on raw materials as a basis of modern technologies. For example, a single ton of mobile phones contains about 300 grams of gold. In the mining industry, one ton of rock needs to be processed to get one gram of the precious metal (Rothe 2010). However, at the end of the utilization phase most mobile phones are disposed in the general waste or remain with their owners without being used. Accordingly, the raw materials contained in the used products are not available to us for a long time. Similarly, solar cells do not work without indium, and without lithium there is no electromobility. The integration of reverse material flows into production networks, however, is not only driven by ecological and economic reasons. Environmental legislation and marketing strategies are also advocating a modern circular economy (Inderfurth 2004). The efficient management of the reverse flow or (re-)use of used products creates significant savings and hence competitive advantages. The real benefit to companies is that material costs are reduced, less waste is produced and output is improved while fewer resources are used. But also producer responsibility is increased to better comply with regulatory guidelines and, last but not least, a major contribution is made to life cycle assessment. This is why new and innovative ways are needed to efficiently use raw materials.

Reverse material flows often pose particular problems on companies, as the reverse flows need to be integrated or newly created and coordinated with the existing production network. Lack of planning reliability, specific customer needs, competitive dynamics and regulatory intervention into the market economy are additional challenges to which companies must respond adequately and without delay. Thus, methods to cultivate complexity in order to cope with these challenges are needed.

If direct reuse is to become an integral part of economy, it is necessary to calculate customer demand while taking the inventory levels and the expected future return flows into account. Prerequisite is an optimal inventory management. The focus of this paper lies on the specification of inventory levels considering reverse material flows for the direct reuse of mobile and durable capital goods, such as construction or production equipment.

2. STATE OF THE ART

For a long time now, the typical approach of businesses in the manufacturing industry has been to ignore used products (Thierry, Salomon and Van Nuen 1995). In recent years, however, this attitude has completely changed. At present, most recycling for the sustainable use of raw materials is actually downcycling, which merely delays the disposal as waste. Examples for this approach are polystyrene used as porosity-enhancing additive in bricks; polyester used as insulating material made of recycled fibers; or PET plastic bottles for the manufacture of benches. To counteract this tendency, it is essential to hold products in the economic system as long as possible and at the highest possible level of value creation. The cradle-to-cradle design developed by Braungart and McDonough is an important approach that imitates natural models for the design of production systems to achieve environmental and commercial advantages (Braungart and McDonough 2009). This approach describes the conditions under which both technological and biological cycles are economically viable. Guide and van Wassenhove claim that the reverse flow and the reuse of products help to combine economic goals with sustainable management (Guide and van Wassenhove 2009). The integration of reverse material flows, however, increases the complexity of the planning process. Closed value chains across multiple business units require an interdisciplinary perspective and appropriate planning and control methods (Abbey and Guide 2012). A challenge in the modeling process is to consider uncertainties resulting from the implementation of reverse material flows. These uncertainties have to do with deadlines, quantities, or quality, and increase complexity within the system (Spengler, Stölting and Ploog 2004). In science, numerous deterministic models exist for the planning and control of closed value networks, but they do not take full account of the diversity of the uncertainty values. Stochastic models, by contrast, use vectors to integrate and consider the entire range of uncertainty values within the model. At the moment, only few approaches focus on the integrated planning of closed value networks and not only on a specific operational issue (Ilgin and Gupta 2010). This paper describes a stochastic approach that takes into account not only profit maximization at optimum inventory levels but also environmental aspects as well as uncertainties.

3. RESOURCE EFFICIENCY THROUGH DIRECT REUSE

Berger and Finkbeiner define raw material efficiency as the ratio between economic value added and raw material input (Berger and Finkbeiner 2008). With direct reuse, the added value remains constant while the resource input is reduced, thanks to the fact that a product may have multiple temporary uses. This way, closed value networks are evolving that can be integrated into the existing production network and are independent of external service providers.

This approach holds great potential especially with a view to durable and mobile capital goods, for example machinery, construction or electrical equipment. In case of such products, the life cycle of entire products, individual assemblies, or components does not come to an end after the use phase but instead they can be offered for reuse.

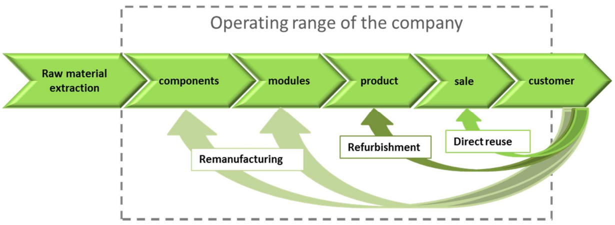

Figure 1: Operating range of companies

At the end of their service life, the products are returned to the manufacturers, who, depending on the condition of the products, decide whether they can be directly reused, if they need refurbishment or if individual components have to be remanufactured. The challenge in planning materials with different flow directions is to identify the optimum inventory level for a company in order to meet demand in an economically optimal way. The role of material flows is essential here, because the reverse material flows of the future will be included in scheduling to meet customer demand.

4. A METHOD FOR THE DETERMINATION OF COST-EFFECTIVE INVENTORY LEVELS CONSIDERING REVERSE MATERIAL FLOWS

It is a complex task to find the right balance in determining cost-effective inventory levels. With direct reuse, complexity rises because of the reverse material flows. To manage the processes while keeping the planning effort low, a defined description of the procedure is required. The objective is to increase the efficiency of the planning process that determines the inventory levels, while taking the reverse material flows into account.

This approach introduces a simple model of a Markov chain indicating the probability of events occurring in the future (Moellering 2007). The factors influencing the inventory levels of direct-reuse products are described in the following. An important parameter in the calculation of the optimal inventory level is customer demand. Being a random variable, it is expressed by the parameter λ as specified by the Poisson distribution. A Poisson process is a stochastic process named after Siméon Denis Poisson. It counts the frequency of certain random events in a given time interval, where N(t) indicates the number of events in the time interval [0,t]. With direct reuse, the temporary periods of use cannot be calculated so that they are specified as $1/\mu$ periods, while π indicates the probability of material availability for direct reuse. The amount paid by the customer for the time a product is used is defined as p. If no products are available for direct reuse, it is assumed that the customer is not willing to wait. It should be noted that it is always the responsible staff member who decides how to manage the reverse material flows. If an order request comes in for which the customer is not willing to wait and no item is on stock and/or the scheduled reverse material flows are delayed, then a decision must be made whether to release a production order or to reject the order request. However, material not sold to a customer will entail warehousing costs of c per period. These costs involve, for instance, tied-up capital or depreciations.

The physical inventory at the time of t is described by the parameter M_t. The inventory currently available is described by M_t^+ = max [0,M_t], while the unfulfilled customer demand is defined by M_t^- = -min [0,M_t].

The key question to be answered is: „How much material for direct reuse should be stockpiled to be able to fill customer demand in the best possible and most economically advantageous way“.

The probability of material availability $\pi_0, \pi_1, \ldots, \pi_M$ can be deduced using the following system of linear equations (Arnold and Furmans 2005).

$$\lambda\pi_1 = M\mu\pi_0 \quad (1)$$

$$\pi_i(\lambda + (M - i)\mu) = (M - i + 1)\pi_{i-1} + \lambda\pi_{i+1} \quad (2)$$

$$i = 1, \ldots, M - 1$$

$$\lambda\pi_M = \mu\pi_{M-1} \quad (3)$$

The probability of material availability π_i can change if material is taken out of stock or added to stock from reverse material flows. These two states are equal to $i - 1$ and $i + 1$, dependent on i. Considering

$$\pi_i = \frac{M!}{(M-i)!}\left(\frac{\mu}{\lambda}\right)^i \pi_0 \quad (4)$$

together with

$$\sum_{i=0}^{M} \pi_i = 1 \quad (5)$$

allows deducing the following probability of the target function:

$$\pi_0 \left[\sum_{i=0}^{M} \frac{M!}{(M-i)!(\frac{\mu}{\lambda})^i}\right]^{-1} \quad (6)$$

Taking this as a basis, the following formula is used to determine the most economically advantageous inventory level $RS(M)$ for direct reuse.

$$RS(M) = -cM + \lambda p(1 - \pi_0(M)) \quad (7)$$

The profit gained from direct reuse depends on customer demand and thus on sales and the probability of material availability $(1 - \pi_0)$ at the time of customer demand after deduction of the warehousing costs. Accordingly, the optimum inventory level M should be increased as long as the resulting profit is rising. The next section will present a case study to illustrate the applicability of the approach.

4.1. Case study

This case study assumes that 10 customer order requests are received every month $(\lambda = 10)$. The average temporary period of use by the customer is 3 months $(\mu = 0{,}25)$. The probability of material availability can be deduced from customer demand (i.e. the number of customer order requests) and the average temporary period of use. In this case, the calculation is $\pi_0 = 0{,}36016444$. Monthly costs for depreciation, inventory holding, etc., amount to €100 $(c = 100)$. The monthly revenue from direct reuse amounts to €120 $(p = 120)$.

$$RS(M) = (120 - 100) * 30 - 120(1{,}97791872)$$
$$RS(M) = 600 - 237{,}3502464$$
$$RS(M) = 362{,}6497536$$

The maximum profit to be achieved for the given assumptions is €362.65. From this, it can be concluded that the optimum inventory level for fulfilling customer demand in the best possible way, while achieving maximum profit, is achieved at $M = 30$. Figure 1 shows a curve indicating the optimum of profit and inventory levels.

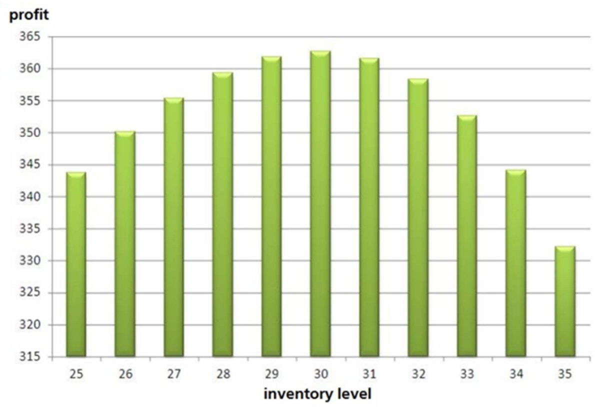

Figure 2: Ratio of inventory to profit in closed value networks

This approach is also applicable for equipment from the energy sector, which is available for temporary use. For example, mobile biomass heating systems or energy storage media in form of batteries can be provided to customers in a flexible and temporary way. Using the described approach, the revers material flows can be calculated and effectively used in closed value networks without reducing the value level. Consequently, a sustainable development in providing renewable energy and a valuable contribution to the environmental performance is being made.

5. CONCLUSION

The presented approach can be used to determine an optimum inventory level taking direct reuse into account. To this end, a stochastic approach considers the occurrence probability for reverse material flows. As direct reuse is not limited to a specific industry, the procedure can be applied to any inventories of durable and mobile capital goods. In addition, the procedure helps to master the complexity in planning and controlling closed value networks. Reduced material consumption, an increase in sales at constant resource deployment, and a reduction of the amount of waste generated are only a few of the possible benefits to companies resulting from direct reuse. Customers profit from the flexibility offered by direct reuse, which allows them to use material temporarily and to pay only for the period of utilization. To ensure a sustainable circular economy and a more effective use of raw materials, it is necessary to address the issue very early at the product development stage. Products must be designed so that they do not become waste and that, after the use phase, the contained raw materials can be continuously and, if possible, fully reused at the same quality. The long-term objective is to make sure that 100 percent of the material inputs end up in the product and are not turned into waste or emissions.

AUTHORS BIOGRAPHY

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REFERENCES

Abbey, J.D., Guide, V.D.R., 2012. Closed-Loop Supply Chains. In: P. Bansal, A.J. Hoffman, eds. *The Oxford Handbook of Business & the Natural Environment*. New York: Oxford University Press, 290-309

Arnold, D., Furmans, K., 2005. *Materialfluss in Logistiksystemen*. 4th ed. Berlin, Heidelberg: Springer Verlag.

Berger, M., Finkbeiner, M., 2008. Methoden zur Messung der Ressourceneffizienz. In: K.J. Kozmiensky, D. Goldmann, eds. *Recycling und Rohstoffe*. Neuruppin: TK-Verlag, 107-130.

Braungart, M., McDonough, W. 2009. *Cradle to Cradle – Remaking the Way We Make Things*. London: Vintage Books.

Guide, V.D.R., van Wassenhove, L., 2009. The Evolution of Closed-Loop Supply Chains. *Operations Research* 57 (1), 10-18.

Ilgin, M.A., Gupta, S.M., 2010. Environmentally conscious manufacturing and product recovery (ECMPRO): A review of the state of the art. *Journal of Environmental Management* 91 (3), 563-591.

Inderfurth, K., 2004. Product Recovery Behavior in a Closed-Loop Supply Chain. In: H. Dyckhoff, R. Lackes, J. Reese, eds. *Supply Chain Management and Reverse Logistics.* Heidelberg: Springer Verlag, 91-114.

Moellering, K., 2007. *Inventory Rationing – A New Modelling Approach Using Markov Chain Theory*. Thesis (PhD). Wilhelms-Universität Münster.

Rothe, P., 2010. *Schätze der Erde – Die faszinierende Welt der Rohstoffe*. Darmstadt: Primus Verlag.

Spengler, T., Stölting, W., Ploog, M., 2004. Recovery Planning in Closed Loop Supply Chains. In: H. Dyckhoff, R. Lackes, J. Reese, eds. *Supply Chain Management and Reverse Logistics.* Heidelberg: Springer Verlag, 61-89.

Thierry, M., Salomon, M., Van Nuen, J., 1995. Strategic Issues in Product Recovery. *California Management Review* 37 (2), 114-135.