From Sustainable Supply Chains to Closed-Loop Systems: A Critical Overview of Scientific Literature

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RESUMEN

La conciencia ambiental se ha convertido en un elemento crítico en el diseño y gestión de operaciones empresariales. En años recientes la cantidad de elementos que han salido a la luz y dirigido la atención de gerentes se ha extendido ampliamente. El desarrollo sostenible es un componente significativo de alto crecimiento para los tomadores de decisiones que tiene que ver con aspectos ambientales y sociales propios tanto de las empresas como de sus socios en la cadena logística con el fin de permanecer competitivas en los mercados actuales. La gestión de cadenas de suministro verdes (*Green Supply Chain Management*, GrSCM) emerge pues como un enfoque interesante para las empresas vinculadas en la aplicación de principios de gestión ambientales y se convierte en un camino para abordar los problemas de sostenibilidad empresarial. Como parte de este enfoque, la logística verde busca la mejor manera de producir y distribuir bienes de manera sostenible y por consiguiente la logística de reversa (*Reverse Logistics*, RL) es considerada como uno de los aspectos clave en la gestión logística verde. Como resultado, surge una gran necesidad de estudiar la logística verde a lo largo de la cadena logística. Inicialmente, este artículo presenta varias definiciones y provee una mirada general de la cadena logística sostenible a través de la logística de reversa y el enfoque de cadenas logísticas cerradas (*closed-loop supply chains*). Posteriormente, este artículo introduce temas actuales de investigación en cadenas logísticas cerradas. Por lo tanto, el objetivo de este trabajo es integrar dos conceptos: procesos de logística inversa con sistemas de cadenas logísticas cerradas con el fin de entender mejor la relación en ellos y contribuir al conocimiento y práctica en la medición y control de cadenas logísticas.

Keywords: cadena logística sostenible, logística inversa, logística verde, sistemas cerrados

ABSTRACT

Environmental consciousness has become critical in the design and operations management. In recent years, the sort of issues that have come to light and drawn the attention of managers has extended staggeringly. Sustainable development is a significant component of growing interest for managers who have to address with social and environmental issues related to the own company as well as their supply chain partners, just to remain competitive in an increasingly aware world. Green Supply Chain Management (GrSCM) emerged as an important approach for enterprises involving the application of environmental management principles to the supply chain and showing as a new way to address the sustainability challenge. Being part of this approach, green logistics looks for the best way to produce and distribute goods in a sustainable way and hence Reverse Logistics (RL) is consider as one of the key aspects of green logistics management. As a result, there is a need to study reverse logistics across supply chains. At first, this paper takes a look at several definitions and provides a general view from sustainable supply chains through reverse logistics to closed-loop supply chains. Further the paper introduces current research topics of closed-loop supply chains and provides an overview of the single papers. Therefore, the aim of this paper is to integrate two concepts: RL process with closed-loop systems to better understand the relation between both and contribute to the knowledge and practice of measuring and controlling sustainable supply chains.

Keywords: sustainable supply chain, reverse logistics, green logistics, closed-loop systems

1. INTRODUCTION

Over the last decade, the sort of issues that have come to light and drawn the attention of managers has extended staggeringly. Instead of considering just basic criteria, such as costs, quality and delivery, supply chain managers must handle a complex range of components that cover the product and the process on the upstream and downstream side of the supply chain (Dyckhoff et al., 2004). Sustainable development is known as a very important component of growing interest for managers who have to address with social and environmental issues related to the own company as well as their supply chain partners, just to remain competitive in an increasingly aware world and markets.

Public scrutiny has increased as consumers have become more knowledgeable of the fact that it is not only the end product, but also the supply chain that need close observance and monitoring. Therefore, sustainable supply chain management can be defined as the management of material and information flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e. economic, environmental and social, and at the same time stakeholder requirements into account (Seuring,2008).

Hence, enterprises have been more and more concerned with "green operations", and identified as a strategic issue (Halabi et al., 2010). Green logistics is part of Green supply chain management (GrSCM) and is concerned with producing and distributing goods in a sustainable way, taking account of environmental and social factors (Sbihi and Eglese, 2007). Accordingly, the aims of Green Logistics are associated with the economic impact of logistics policies inside the organization and with the vast effects on society, such as the effects of pollution for the environment.

Green Supply Chain Management (GrSCM) emerged as an important approach for enterprises to improve performance on economic and environmental dimensions (Zhu and Sarkis, 2004). GrSCM is defined as the integration of environmental thinking into supply chain management, including product design, supplier selection and material sourcing, manufacturing processes, product packaging, delivery of the product to the consumers, and end-of-life management of the product after its use (Srivastava,2007). As such, GrSCM ranges from green product design to a closed loop product return processing and requires high-level and detailed planning and steering of complete supply chains on an end-to-end basis (Sundarakani, 2010). As an outcome, GrSCM can reduce waste, minimize pollution, save energy, conserve natural resources and reduce carbon emissions (Bloemhof-Ruwaard et al.,1995; Parry et al., 2007).

GrSCM covers an approach known as product stewardship and includes activities such as Reverse Logistics (RL), product recovery and remanufacturing. All of these activities require more coordination with immediate customers and/or end–consumers, along with greater interaction with suppliers when designing and developing new products (Vachon et al, 2001).

Reverse logistics involves the logistics activities all the way from used products no longer required by the consumer to products again usable in a market. According with Pirachican et al. (2009) the recovery of goods at the end of their lifetime creates a backward flow of materials from any link of the supply chain, with the aim of recovering or re-integrating goods to the supply chain. Otherwise, they are disposed in such a way that the company can benefit financially, environmentally, and can generate added value.

The RL process is found either as a subset of closed-loop systems or standing alone. This includes full coordination and control, physical pick-up and delivery of the material, parts, and products from the field to processing and recycling or disposition, and subsequent returns back to the field where appropriate (Blumerg, 2005). The development of a RL system requires an analysis that allows the viability of both strategic and operational issues (Diaz, 2004). At the strategic level, the objectives are to reduce costs, to identify new business opportunities and to improve the relationships with clients (Halabi et al., 2010).

Nowadays, consumers demand for clean manufacturing and recycling. Kannan et al. (2009) explain that customers and retailers expect original equipment manufacturers to set up a proper reverse logistics system and expected the returned products to be processed and recovered in an environmentally responsible way. At the same time, a well-managed reverse logistics programme can provide important cost savings in procurement, disposal, inventory carrying and transportation. As stated before, there is a need to study reverse logistics across supply chains. Therefore, the aim of this paper is to integrate two concepts: RL process with closed-loop systems to better understand the relation between both and contribute to the knowledge and practice of measuring and controlling sustainable supply chains.

This paper is organized as follows: the second section contains several definitions from sustainable supply chain to closed-loop system, covering green logistics and the integration with reverse logistics. The third section shows closed-loop considerations and research topics and the last section presents conclusions and recommendations for further research.

2. DEFINING THE TERMS: FROM SUSTAINABLE SUPPLY CHAIN TO CLOSED-LOOP SYSTEM

Environmental consciousness has become critical in the design and operation of globally integrated supply chain networks (Sundarakani, 2010). A new body of literature places environmental Supply Chain Management (SCM) within Industrial Ecology (IE). IE can be defined as a "new system for describing and designing sustainable economies"(Kovács, 2008). According to Boons and Baas (1997), IE's integrated chain management would need to follow a particular material from its raw material extraction to end disposal. Important topics to highlight in IE are the life cycle assessment and extended producer responsibility, both boost the view on Corporate Environmental Responsibility (CER) over several echelons upstream and downstream in the supply chain.

As stated by Linton et al. (2007) sustainability must integrate issues and flows that go beyond the core of the supply chain management such as: product design, production, distribution, end of life products and recovery processes. These definitions are useful to introduce us to the sustainable supply chain management framework.

- *Product design:* look for methodologies to include environmental implications at the product design level. These findings can serve in the conclusion on how to design a product with the aim of minimize its environmental impact over its usable life afterwards. According to Barbosa (2009) the integration between the product design and the processing phase should be explored so as to diminish environmental impacts and guarantee the long-term sustainability.
- *Production:* research at this stage should concentrate efforts in the development of cleaning production which aims to reduce by-products that may damage the environment and human health. Barbosa (2009) suggests that process technologies should be designed and operated to easily incorporate reusable products aligning in this way with the need of decreasing the use of resources.
- *Distribution*: transportation appears as one of the main contributors to the supply chain footprint. The reduction of greenhouse gases through the use of cleaner transportation modes coupled with an optimal definition of the supply chains structures will contribute positively towards sustainability (Linton et al., 2007).
- *End-of-life products and Recovery processes:* an end-of-life management of the product after its use is an area that has become a field of rapidly growing importance. The product design process has a great influence on how a product can be re-used, remanufactured, recycled, incinerated or disposed of. According to Barbosa (2009) the work on how to capture the value remaining in products at the end of its life should be extended.

The in-breath in each one of these areas is out of the scope of the supply chain management but their study is definitely related to the supply chains systems (Barbosa, 2009). Efforts on both sides will support the goal of responsible care as stated by Grossmann (2004). The development of systematic methods and tools that guarantee the design of environmental benign products and processes coupled with sustainable supply chains is therefore the goal to accomplish (Barbosa, 2009).

Green supply chain management (GrSCM) emerged as an important approach for enterprises involving the application of environmental management principles to the supply chain and showing as a new way to address the sustainability challenge. Being part of this approach, green logistics look for the best way to produce and distribute goods in a sustainable way.

2.1 Green Logistics

Green Logistics activities include measuring the environmental impact of different distribution strategies, reducing the energy usage in logistics activities, reducing waste and managing its treatment (Halabi et al., 2010). For achieve the goals stated before, Reverse Logistics is considering as one of the key aspects of Green Logistics management. As stated by Pirachican et al.,(2009) the practice of Reverse Logistics enables the recovery of goods at the end of their lifetime in a way that is efficient and is also utilized to recover goods that are no longer useful for the consumer. Srivastava (2007) proposed a framework to classify the different dimensions of green logistics/supply chain management and the integration with Reverse Logistics (see fig.1).

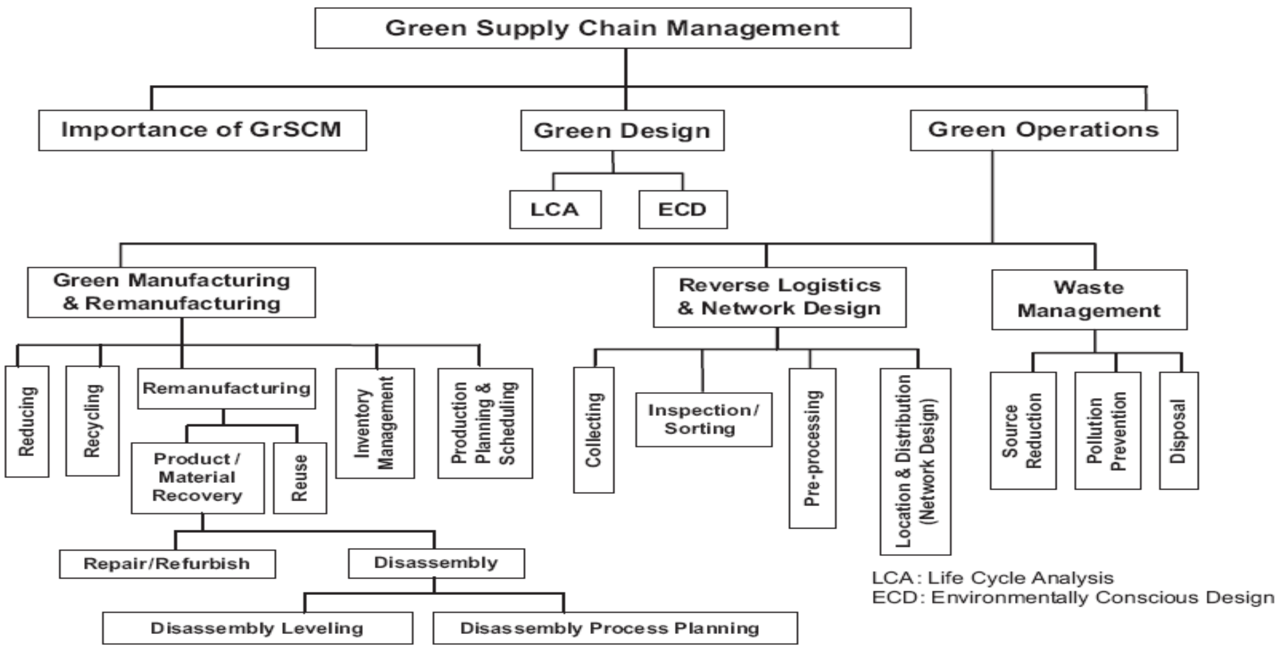

Figure 1. Classification of existing literature on green supply chains. Source: Halabi et al. (2011).

Dowlatshahi (2000) explains Reverse Logistics as "a process in which a manufacturer systematically accepts previously shipped products or parts from the point for consumption for possible recycling, remanufacturing or disposal". According to the Reverse Logistics Executive Council (RLEC) (Rogers,D. and Tibben-Lembke, 2007) reverse logistics (RL) is defined as "the process of planning, implementing, and controlling the efficient and cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal". Kannan et al., (2009) report Reverse Logistics as the term most often used to refer to the role of logistics in product returns, source reduction, recycling, materials substitution, reuse of materials, waste disposal, and refurbishing, repair and remanufacturing.

As an approach for product returns is to create product recovery networks which involve collection of used products from the customer back to the supply chain, reprocessing and future redistribution to the market (Beamon and Fernandes, 2004). As stated by Fleischmann, (2001) recovery networks encompass a selection of supply chain stages where the recoverer's responsibility begins with the collection of used products and ends with the distribution of recovered products. This reverse distribution can be defined as the collection and transportation of used products and packages. According to Beamon and Fernandes (2004) reverse distribution can take place through the original forward channel, through a separate reverse channel, or through combinations of the forward and the reverse channel.

3. THE CLOSED LOOP CONSIDERATIONS AND RESEARCH TOPICS

management of return flows induced by the various forms of reuse of products and materials in industrial production processes has received growing attention throughout this decade. As stated by Beamon and Fernandes (2004) product returns are the most common aspect of reverse logistics. A primary reason for this is the massive shift in revenue opportunity that now follows each product sale. This leaves some companies seriously considering a 'closed loop' approach to the supply chain that includes product returns, service contract returns, product recalls, used equipment and replacement parts for refurbishment, as well as reuse or sale as raw material.

Closed-loop supply chains, embodying remanufacturing and reverse logistics, might be expected to an important means to enable business to meet the growing demands of corporate social responsibility, and to meet wider social goals to reduce the resource-intensity of contemporary economic life (Desai and Riddlestone, 2002). Wells and Seitz, 2005 consider that closed loops offer opportunities to achieve the so-called "triple bottom line" of social, business and environmental benefits.

In conclusion, it is significant to know that in general terms, closed loops are conformed by two supply chains: a forward and a reverse chain whereby a recovered product re-enters the traditional forward chain.

Usually in a forward supply chain, the customer is the end of the process. However, a closed-loop supply chain includes the returns processes and the producer has the target of capturing added value and further integrating all supply chain activities. According to Guide and Harrison (2003) closed-loop supply chains include traditional forward supply-chain activities and the additional activities of the reverse supply chain. These additional activities include:

- Product acquisition to obtain the products from the end-users
- Reverse logistics to move the products from the points of use to a point(s) of disposition
- Testing, sorting and disposition to determine the product's condition and the most economically attractive reuse option
- Refurbishing to enable the most economically attractive of the options: direct reuse, repair, remanufacture, recycle, or disposal
- Remarketing to create and exploit markets for refurbished goods and distribute them

As stated by Fleischmann et al., (2000) the increasing interest in re-use of products and materials is one of the consequences of growing environmental concern through the past decades. Waste reduction has become a prime concern in industrialized countries. Due to depleted landfill and incineration capacities, efforts are made to re-integrate used products into industrial production processes for further use. Several countries have enforced environmental legislation charging producers with the responsibility for the whole life cycle of their products (Thierry,1997). Take-back obligations for a number of product categories like electronics, packaging material, and cars and some of the measures taken (Fleischmann et al., 2000).

Schultmann et al., (2004) present on " Integrating Spent Product's Material into Supply Chains: The recycling of End-of-Life vehicles as an Example", different design options for the reverse supply chain that are analyzed by the combination of facility location planning with vehicles routing in an integrated approach, where the automotive cycle is used as an example.

In this paper Schultmann et al., (2004) stated that the background of the Supply Chain Management (SCM) framework can be characterized by the term linear economy (see fig.2): emphasis is on utilizing natural resources for the production of goods, while end-of-life options are mainly incineration or disposal. Without take-back obligations for spent products, the producer usually coordinates the process chain beyond the point of sale. Nowadays, with new legal policies emerging, more and more producers have had to apply take-back obligations. As a result, this effect will change the SCM framework, which can then be characterized as closed loop economy, this change involves two major adaptations:

- Instead of single-stage disposal options for end-of-life or landfilling, multi-stage, enhanced reprocessing techniques are necessary to transfer spent products components into secondary material that meets the quality requirements for reuse in technical applications. Therefore, an additional supply chain in reverse direction, a Reverse Supply Chain as defined before, becomes necessary.

- When this secondary material is integrated into the genuine production process, facing tasks as recovery and secondary material processing (see fig. 3), in order to avoid downcycling, feedback effects to the supply chain with regard to adaptations in time and quantity will take place. Apart from establishing the reverse supply chain, coordinating both chains becomes necessary.

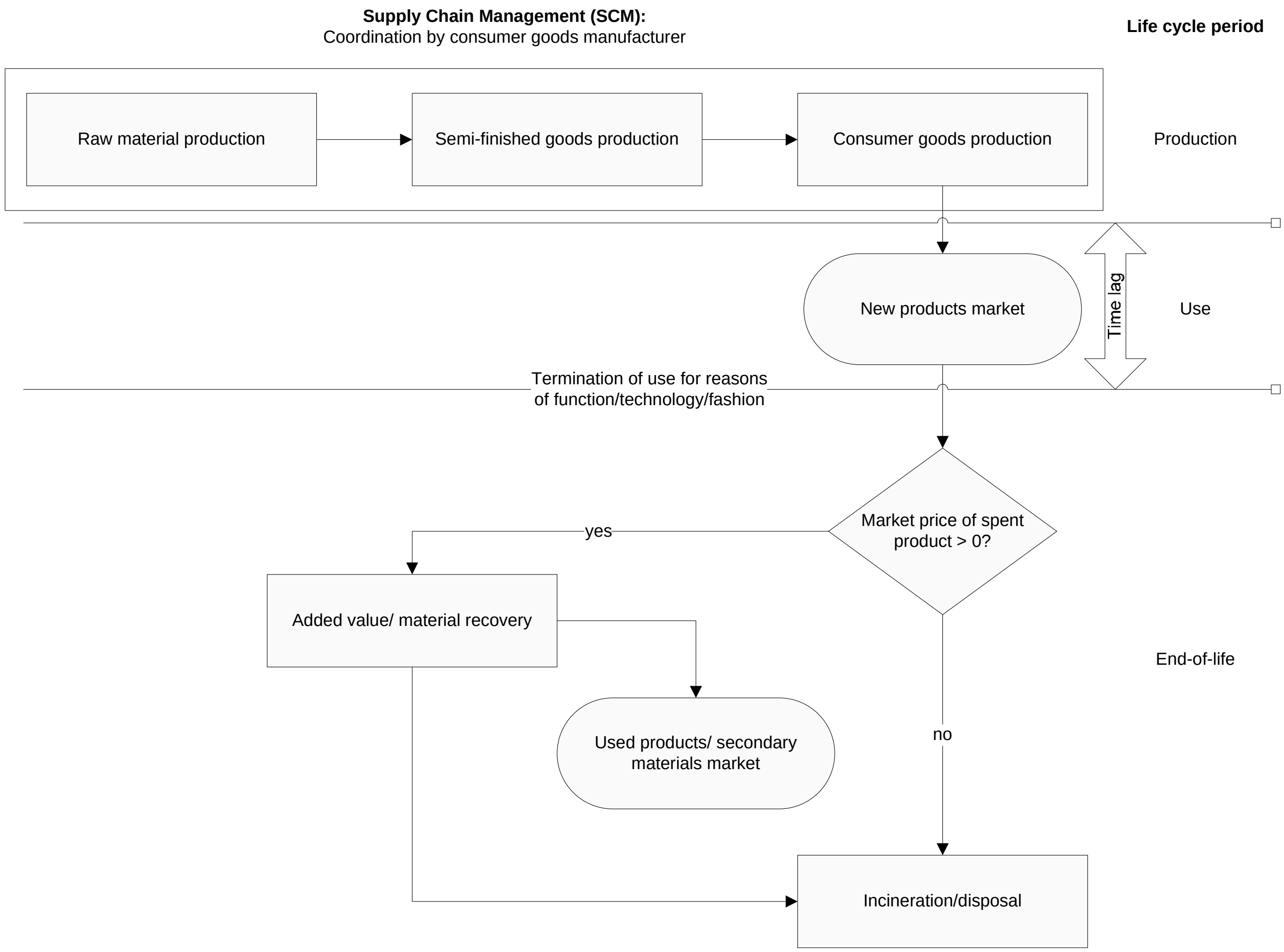

Figure 2.Linear economy. Adapted from: Dyckhof et al.(2004).

Considering the average time gap between production and recovery, the future tendency of quantity development can be determined. According to Schultmann et al., (2004) with this framework, planning variables are determined by the facility location, the capacity, and the midterm extension options for sites in which reprocessing will be performed. As recovery of plastics from spent vehicles requires area-covering backhauling, vehicle routing tasks have to be addressed simultaneously. The interdependencies between these tasks require a combined approach.

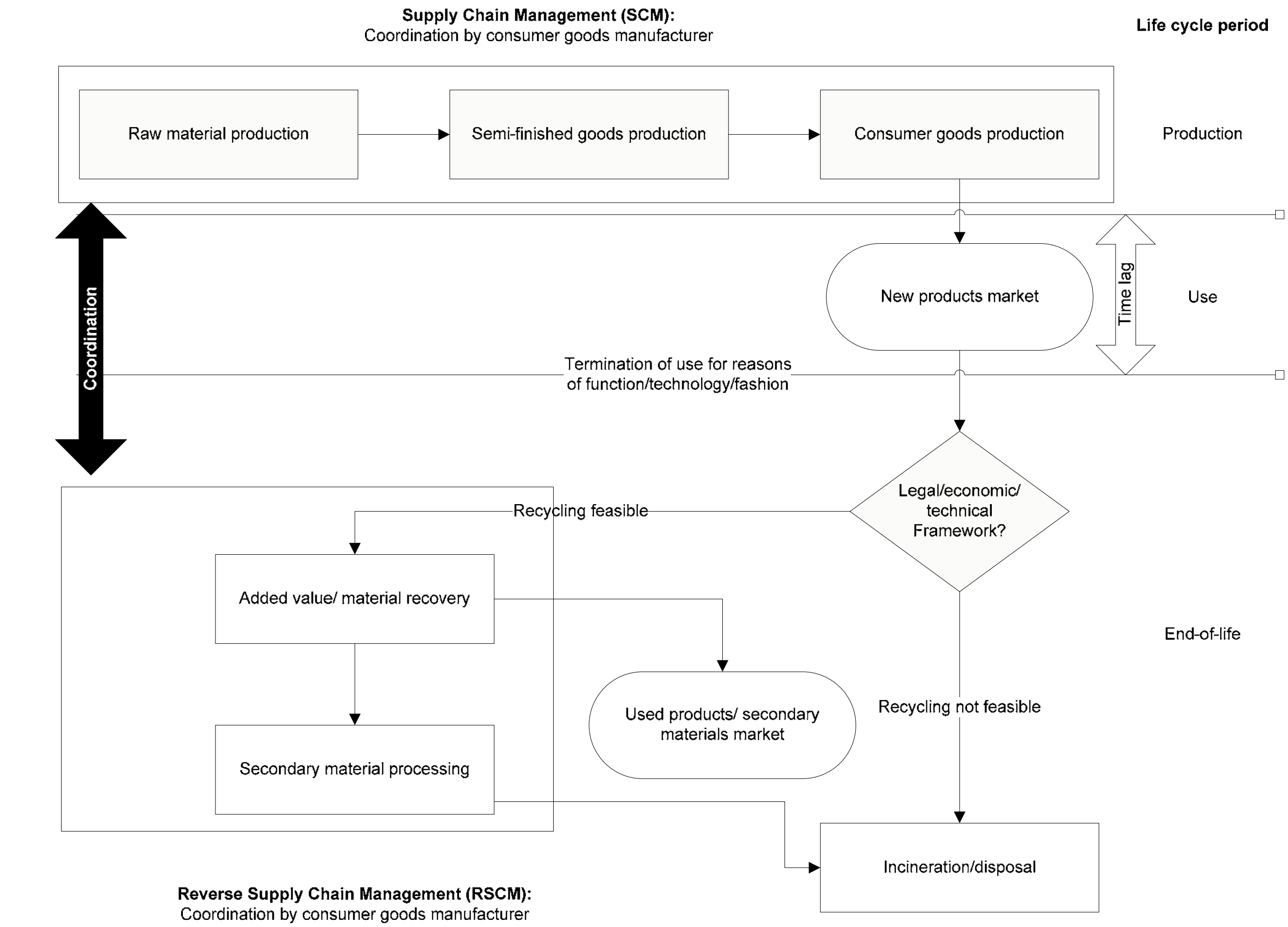

Figure 3.Closed loop economy. Adapted from: Dyckhof et al.,(2004).

While the previous paper includes the automotive industry as additional linking element, the following paper connects products repurchasing and recycling with inventory management. As stated by Fleischmann et al., (1997) inventory control is a fundamental activity in closed-loop supply chains, particularly for remanufacturing processes. Several models have been developed in the literature where the goal is generally to optimize cost or profit and to find the optimal order quantity for an integrated production and remanufacturing. Inventory control requires appropriate control mechanisms to integrate the return flow of used products with the material planning for the forward flow.

The study of Inderfurth (2004) on the "Product Recovery Behavior in a Closed-Loop Supply Chain" is confronted with uncertainties. The analysis is presented for a closed loop system of original equipment manufacturers OEMs. Here a manufacturer of original products is also engaged in remanufacturing used products taken back from its customers. For this type of closed loop supply chain, which is characterized by uncertainty of demands and product returns, the optimal recovery and production policy is evaluated. In this context, it is by no means obvious how different sources and levels of uncertainty affect the recovery behavior, i.e. specifically the tendency to remanufacture used products for re-use purposes instead of disposing them.

Fleischmann and Minner, (2003) review mathematical models on "Inventory Management in Closed-Loop Supply Chains". They follow a standard structuring of traditional inventory theory and discuss applications to closed-loop settings for each case. Their analysis is focused on highlighting novel characteristics entailed by a closed-loop supply chain structure, in terms of both mathematics and business implications. In this context, Richter and Dobos, (2004) evaluate a general model for "Production-inventory control in an EOQ-type reverse logistics system" which allows for repurchasing and recycling or disposing of used items. The analysis shows that the mixed strategies of combining production and recycling are dominated by pure strategies.

4. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The recompilation of the considered papers covers essential research topics that provide an overview of the extension of supply chains to closed-loop systems covering from conceptual framework to modeling and algorithms. The challenge of sustainable supply chain management is how to run a viable sustainable chain taking the three dimensions of sustainable development, i.e. economic, environmental and social into account.

Green Supply Chain Management (GrSCM) emerged as an important approach for enterprises involving the application of environmental management principles to the supply chain and showing as a new way to address the sustainability challenge. Being part of this approach, Green Logistics look for the best way to produce and distribute goods in a sustainable way.

There are many reasons for the growing interest in Reverse Logistics. The most relevant reasons are the growing concern for the environment and cost reduction. A well-managed reverse logistics program can offer significant cost savings in procurement, disposal, inventory carrying and transportation. This leaves some companies seriously considering a 'closed loop' approach to the supply chain that includes product returns, service contract returns, product recalls, used equipment and replacement parts for refurbishment, as well as reuse or sale as raw material. Therefore, in general terms, closed loops are conformed by two supply chains: a forward and a reverse chain whereby a recovered product re-enters the traditional forward chain.

In recent years, several countries have enforced environmental legislation leaving producers with the responsibility for the whole life cycle of their products, thus producers has to take more and more take-back obligations. Some of the measures taken include take-back obligations for a number of product categories like electronics, packaging material, and cars.

Nowadays, the challenge for further research is to apply closed-loop systems in additional type of industries, different from automotive and electronics enterprises, for example, in Agro-industrial companies, such as, dairy and meals, to measure the impact of the role of logistics in product returns, source reduction, recycling, materials substitution, reuse of materials, waste disposal, and refurbishing, repair and remanufacturing.

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