INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

COORDINATING DESIGN DECISIONS FOR PRODUCT, SUPPLY CHAIN AND REVERSE SUPPLY CHAIN

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ABSTRACT

New environmental regulations have extended the producer’s responsibility for a product to the post-consumer stage. Producers are often responsible for the collection and recovery of their end-of-life (EOL) products. In fact, the producer’s conventional supply chain has been extended to integrate reverse logistics activities dealing with EOL products. The economic and environmental viability of recovering EOL products is a daunting challenge for producers. Our literature review shows a scarcity of knowledge about how to design a viable reverse supply chain for recovering EOL products while considering product and supply chain dimensions. This paper presents a methodology for designing a reverse supply chain for EOL products based on coordination among product design, forward supply chain design and reverse supply chain design decisions. When deciding whether to invest in a structured reverse supply chain design and implementation, decision-makers need to fully understand the interactions among these three dimensions.

Keywords: reverse logistics, supply chain design, product design, global cycle house

1 INTRODUCTION

New environmental legislations (WEEE and ELV) combined with current market trends are pushing manufacturers to extend their original supply chains to integrate reverse logistics activities dealing with end-of-life products. In fact, many manufacturers are now doing business in an extended supply chain (Figure 1) that combines their forward and new reverse supply chains. A reverse supply chain can be defined as a logistics network that follows the forward supply chain and tries to create value by remanufacturing end-of-life products. The reverse supply chain, like the forward one, consists of suppliers, a focal manufacturer, distributors and customers. The cores (EOL products) are supplied by the customer, remanufactured by the original equipment manufacturer (OEM) or an independent firm and delivered to same or to another customer. This reverse supply chain can occur several times in a multi-life cycle system.

To stay in business, some manufacturers try to design and implement reverse supply chains, but few have successfully changed their product design and forward supply chains to deal with the problem from inception. The majority of current products are not designed to be remanufactured or recycled. Most forward supply chains do not allow end-of-life product recovery because the products are complex and difficult to disassemble. Materials and components recovered from original products are generally poor quality. Further, the cost efficiency of traditional products has been established for only one life cycle, which makes extending the forward supply chain to recovery activities unprofitable for the original equipment manufacturers.

Best business practices of companies such as IBM, Xerox and Canon, and academic research [1] [2] [3] show that remanufacturing EOL products or modules has great economic, environmental and societal benefits. To assure success in remanufacturing, the original equipment manufacturer must design and implement a reverse supply chain that is economically and environmentally viable. This viability is dependent on how product and forward supply chain are designed.

This paper presents a methodology for designing a viable reverse supply chain based on coordination among product, forward supply chain and reverse supply chain design decisions. The paper is structured as follow: Section 2 reviews the literature, evidence of the meager knowledge available on how to design a viable reverse supply chain. Sections 3 describes our approach for coordinating product, forward supply chain, and reverse supply chain design decisions, and section 4 proposes a research program to test this approach.

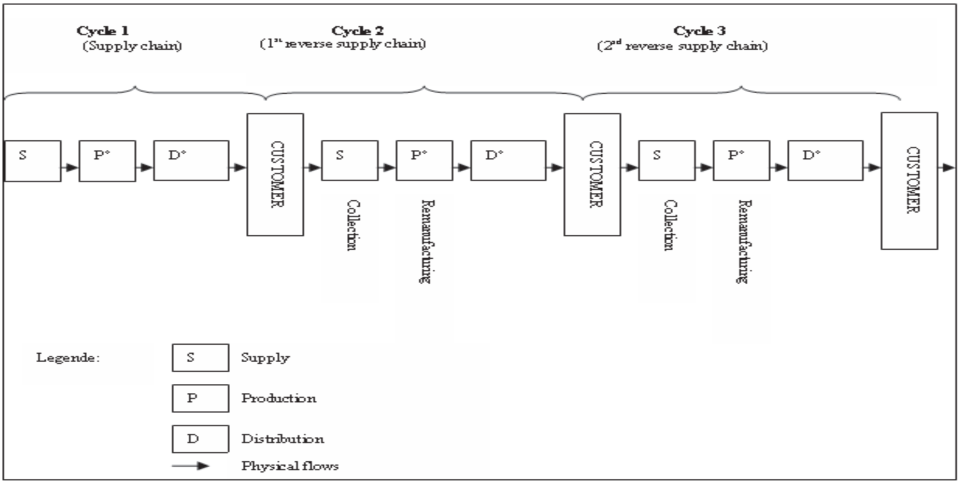

Figure 1 : the extended supply chain

2 LITERATURE REVIEW

2.1 Reverse supply chain design

Economic, technical and legislative events of the past two decades have created academic as well as practical interest in reverse logistics [4] [5] [6]. Given its accepted importance, one might expect that reverse supply chains, where reverse logistics activities dealing with EOL products are carried out, would be clearly defined and reflect a rich tradition of theory development for design and implementation.

On the contrary, a close examination of the literature reveals no clear definition for reverse supply chains and virtually no empirically-based theory that firms interested in reverse logistics can apply to design their own reverse supply chains. Further, the literature pays little attention to the contextual factors that make a reverse supply chain suitable for a particular business. Fernandez et al. [7] argue that "simply mimicking the example of leading firms (e.g. Xerox and IBM), for one reason or other, is not a feasible option for all companies." According to the configurational approach [8], the same focus does not work in all industries, for all products, and for all types of customers. Guide et al. [9] state that "not all closed-loop supply chains (including remanufacturing processes) are the same and each type of system offers different characteristics and managerial concerns."

Even if there is evidence that reverse logistics concepts can strengthen a company's competitiveness, only a few firms have established a profitable reverse SC. They include Kodak, Océ Technologies, Mercedes-Benz, Xerox, ReCellullar, Philips, and Volkswagen. Lack of knowledge may be the reason top management does not spend much effort designing reverse supply chains. Management may also fear the perceived complexity of the process. Krikke et al. [10] state that "the lack of managerial attention very often leads to "quick and dirty" solutions, resulting in inefficient, non-responsive, and sometimes even environmentally unsafe reverse chains".

2.2 Drivers of reverse supply chain design and implementation

There is a consensus in the literature [11] [12] [13] that the macro drivers for designing and implementing a reverse SC are the same as those for sustainable development (economic, environmental and social drivers). Inside each macro driver a variety of micro drivers can be prioritised according to the industrial sector and the company business.

Initially, many reverse SC implementations were driven by ecological arguments such as the need for waste reduction and customer demands. Consequently, many companies have considered product returns as a cost factor from the beginning, but they have started to recognize the potential value of these flows [14], as Rebitzer [15] notes: “The focus of sustainable development (or ‘sustainability’) in industry is shifting from looking at environmental and other impacts as an additional issue with additional costs to an area of opportunity”. According to Geyer and Jackson [16] “the future will belong to those firms whose strategies for product end-of-life management succeed in simultaneously creating both environmental and economic value, a win-win opportunity”. We can conclude from these discussions that an economically and environmentally viable reverse SC is the goal. Although researchers also recognize the social dimension of sustainable development, our research focuses on the economic and environmental dimensions. They are directly correlated to the social dimension since they create jobs and improve the quality of life for all people.

2.3 How to design a viable reverse supply chain?

The reflection on how a firm could design the most appropriate reverse SC to its business leads to the consideration of two interesting dimensions preceding the existence of the reverse SC. These two dimensions are product design and forward SC design. The reverse SC that a firm will design and implement will remanufacture an existing product which is produced and delivered by an existing forward SC. However, neither the product nor the forward SC is designed in a manner that allows remanufacturing.

To overcome this problem, several research communities have studied adapting the product and the forward SC to plan for remanufacturing end-of-life products. In the product design field, research [17] [18] [19] has focused mainly on adapting the product structure to the technical remanufacturing criteria (disassembly, cleaning, durability, etc). Whereas, in the SC design area, research has focused on adapting the forward SC structure to plan for the return flows [20] [21] [10].

While this research is valuable, it deals mainly with narrow problems regarding product and SC design and neglects the big picture that integrates the three dimensions of product, forward SC and reverse SC design. Guide et al. [9] state that “with the exception of Thierry et al. [22], the past research addresses a single aspect of remanufacturing using a single example, e.g. models for inventory control based on automotive parts remanufacturing”. Carter and Ellram [23] confirm this gap in the research, noting the lack of “theoretically grounded and holistic views of reverse logistics”. In fact, the lack of a holistic view of the three design dimensions and how they interact with each other is the main reason for the economic and environmental failure of some reverse SCs.

2.4 Coordinating product, supply chain and reverse supply chain design decisions

Until recently, a firm’s competency in designing innovative products was often enough to insure its market dominance. But in today’s competitive environment, with customers demanding greater product offerings and with the products being offered facing shorter product life cycles, this ability to continually design new products in response to technology or market trends is not a sufficient condition to guarantee firm survival [24].

To improve the competitive advantage of the firm in this more demanding environment, academic researchers have begun studying the benefits of coordinating different design decisions. They have examined how to coordinate product design decisions with manufacturing process decisions, an approach known as “concurrent engineering”. Other research has focused on synchronizing SC and product design decisions [25]. Fine [26] suggested a new paradigm, claiming that “in the era of the temporary competitive advantage, what must be undertaken is three-dimensional concurrent engineering (3-DCE), the simultaneous and coordinated design of products, manufacturing processes, and supply chains”, arguing against Porter’s (1985) notion of sustainable competitive advantage. More recently, researchers have explored the impact of product design characteristics such as durability [27] or modularity [10] [7] on reverse logistics strategy.

A literature review reveals few articles on coordinating product, SC and RSC design decisions. Krikke et al. [10] developed a double-integrated modeling framework, based on mixed-integer linear programming, for SC design with multiple product design options and multiple product recovery options with varying feasibility. “Double-integrated” refers to including forward and reverse SCs as well as multiple objective optimization of SC costs and environmental impacts [10]. Umeda et al. [28] argue that the product design needs to consider the full product lifecycle, including forward and reverse SC processes. To support the design of a lifecycle, Umeda et al. [28] propose a simulation to evaluate product lifecycles from an integrated perspective, including environmental consciousness and economic profitability. They further argue that "because the products have different modular structures, they have different costs and environmental impact functions, in particular for reverse logistics processes. Feasibility for various recovery and disposal processes also varies strongly per design on product, module and component level"[28].

We conclude from our literature review that while there is an obvious interest in coordinating product, SC and RSC design decisions, there is a lack of research on this subject. Our research project explores whether coordinating these design decisions could be a determinant factor for the economic and environmental viability of a reverse SC.

3 METHODOLOGY FOR DESIGNING A VIABLE REVERSE SUPPLY CHAIN

Prior to the presentation of the proposed methodology which is based on the coordination between product design, SC design and RSC design decisions, some basic relationships between these three design dimensions must be highlighted .

All design processes begin with identifying a customer need. R&D uses this information to design a product. The forward SC is designed to produce and deliver this product to the customer. The reverse SC is designed to recover this product at end-of-life. Some existing concepts allow the development the product and the forward SC design to be done concurrently (e.g., concurrent engineering, supply chain management, quality function deployment, and integrated logistics support). These concepts allow the integration of the voices of some internal and external SC actors into product design. This integration process considers the first customer as the downstream limit of the SC. In fact, concepts allowing the integration of reverse SC actors voices' into product design still not exist. To allow reverse SC design to take place concurrently with product and forward SC designs, the voices of the reverse SC designers should be heard along with those of the SC designers (Figure 2).

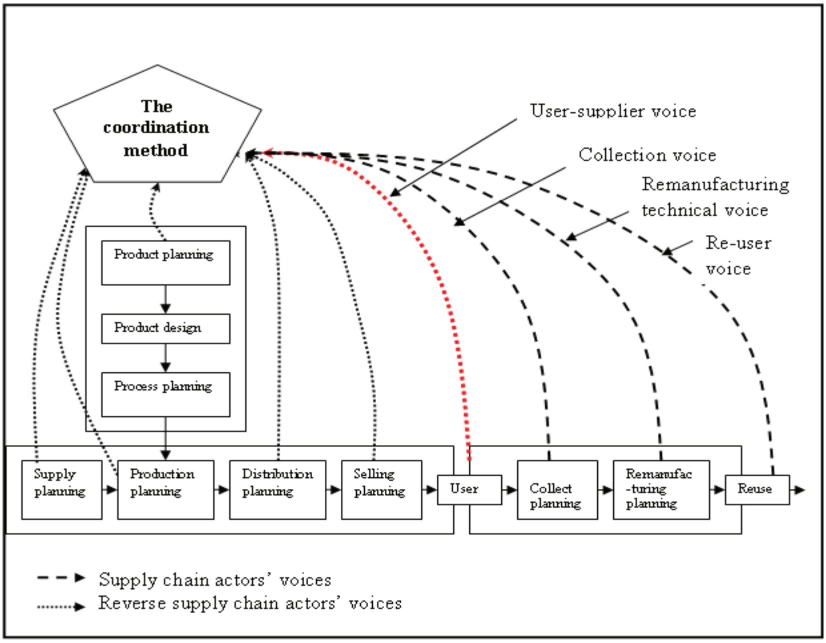

Figure 2 : Involvement of the extended supply chain designers in reverse supply chain development

Our methodology, like the quality function deployment method [29], allow multidisciplinary work focusing on the design of an economically and environmentally viable reverse SC as part of a global system including the product and the forward SC. It is essentially an interface methodology where every design parameter influencing the reverse SC design is translated into the three designs dimensions and evaluated in economic and environmental terms. In the output of the methodology, the designers could determine the points on which they should act to obtain a viable reverse SC.

Every SC, whether forward or reverse, depends on three functional players: suppliers, a focal manufacturer, and customers. The rest of the actors are intermediaries who support SC operations. In the reverse SC, the cores (EOL products) are supplied by the first customer, remanufactured by the original equipment manufacturer (OEM) or an independent firm and delivered to the same or to a second customer. Our proposed methodology first identifies the needs of the second customer who buys the remanufactured product. This represents the customer's conditions for buying a remanufactured product instead of a new one. The literature specifies four generic conditions:

- *Economic cost* must be less than or equal to the new product cost
- *Environmental impact* must be less than or equal to the new product impact
- *Quality* must be equal to the quality of the original new product
- *Upgradeability* must be equal to that of the original new product technology level.

These four conditions form the input of our methodology. To satisfy these conditions, a multidisciplinary team of designers should reflect on the parameters that affect each condition, which they should track through the three design dimensions. To facilitate this work, all the parameters for each customer condition are organised in a sheet we call the "Global Cycle House" (Figure 3), a kind of balanced scorecard. The indicators give the designers a global view so they can control the reverse SC design performance.

The quality and upgradeability parameters should be translated, when possible, to be given economic and environmental evaluations. The economic and the environmental evaluations are done according to activity-based costing and lifecycle assessment methods, respectively. The total evaluation results are compared to fixed limits of cost and environmental impact. The margins between the evaluation results and the fixed limits are the margins of improvement required to reach the customer of the remanufactured products conditions.

For example, to reach the quality condition, the designers should identify the main parameters affecting the quality of the remanufactured product at the product design level (e.g. modularity, durability, etc.), at the forward SC level (e.g. suppliers integration, traceability, leasing contract duration, etc.), and at the reverse SC level (e.g. transportation, warehousing, remanufacturing process, etc.). Because the quality of the remanufactured product is a mix of all these parameters, some parameters need a rational adjustment to find an optimum mix to reach the quality condition. To find the optimum mix, every variation in a quality parameter should be evaluated in economic and environmental terms to insure that the conditions are still respected. The variation in each quality parameter, whether positive or negative, generates a variation in the economic cost and the environmental impact of the parameter compared to the initial situation without remanufacturing. This variation should be considered when evaluating the cost and the environmental impact of a remanufactured product.

This methodology has two main advantages. The first is a global view that allows the design team to easily find the constraining points which determine the economic and environmental viability of reverse SC. The second advantage is the flexibility of the method, which is critical for designing the most appropriate reverse SC for the firm's business.

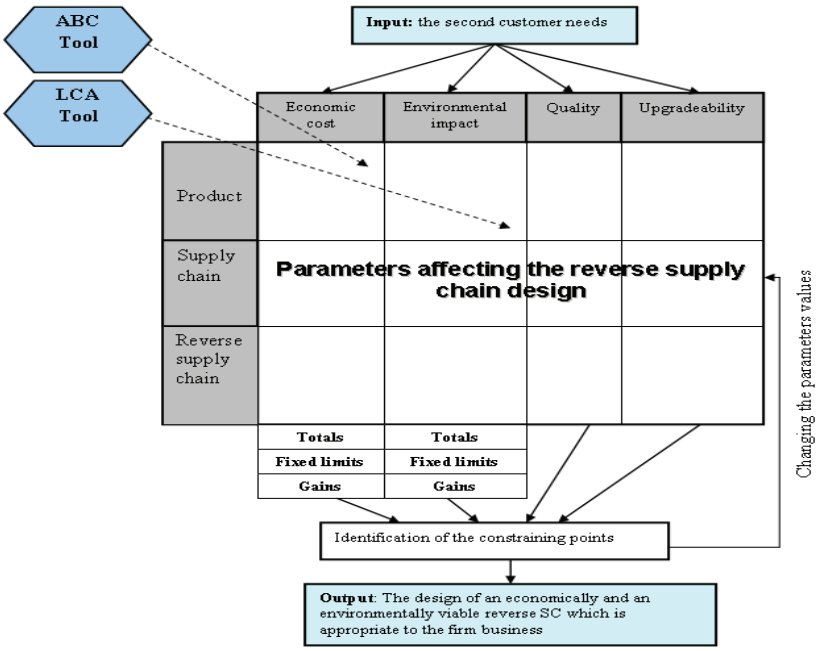

Figure 3 : the Global Cycle House

4 CASE STUDY

4.1 The company presentation

Company Alpha is a French producer of a business-to-business electrical-and-electronic-equipment appliance. Several product categories are produced to meet the needs of small and large customers. Alpha products are covered by the Waste Electrical and Electronic Equipment (WEEE) Directive, under product category 3 and should comply with the following recovery rates: 75 percent per weight of recovery, 65 percent per weight of reuse/recycling. Alpha is also responsible for recovering its end-of-use products since it has a professional market.

4.2 The company project

Even before the WEEE Directive, Alpha established its own take-back system for recovering its end-of-lease products. Due to product confidentiality, French legislation requires companies operating in Alpha's market to lease and to recover their end-of-lease products. The recovery process for Alpha's products is described below.

The end-of-lease products are recovered by company agents in charge of customer service. The cores (the recovered products) are consolidated by the company's local agency before reaching the central warehouse. These operations can take from one-to-four months. Depending on the product references and categories, recovered products exceeding the warehouse stock limits are sent directly to a local recycling center while the remainders are stored for several months before being refurbished or recycled. A small number of collected products are refurbished and leased during promotional campaigns.

Initially, Alpha considered the recovery system as a cost generator but the company has become increasingly aware of the potential value of its end-of-use products. Alpha is now interested in developing a remanufacturing activity that will be part of its value-creating activities. The main questions the company faces are how to design a reverse SC appropriate to the company business and how to ensure that it will be operational, environmentally effective and economically efficient.

4.3 Case study research plan and the Global Cycle House (GCH) application

Our research team became temporarily embedded in Alpha's reverse SC design program. The Global Cycle House (GCH) methodology was tested by applying it to this program. The program first analyzed the existing product, the SC and the recovery system. The second stage involved constructing several scenarios using varying parameters at the level of the three design dimensions (product, FSC and RSC). Every scenario had an economic, environmental, quality and upgradeability assessment. The final stage was to choose the scenario that best allowed the company to meet customer needs for the remanufactured product and insured the economic and environmental viability of the new reverse supply chain.

4.4 Case data and sources

We conducted interviews to collect data with the managers responsible for eco-design, production, logistics, quality and marketing. More interviews with Alpha's suppliers, customers, and distributors are planned. Other sources of data are based on extensive participant observations, archival records, and company documents.

4.5 Content validity

The GCH is filled with generic parameters extracted from our analysis of the literature about eco-design and reverse logistics. The list of parameters is not exhaustive and it can be adapted to other companies. The evaluation of the parameters is extracted from the interviews and other sources of data. By varying the evaluation of the parameters we constructed several scenarios whose pertinence and validity will be validated by multidisciplinary meetings with company managers. The final meeting should allow us to choose the best scenario.

4.5 Results and discussion

Several scenarios were constructed by varying the number and lifespan of the reused modules, the leasing contract duration and the reverse SC network structure, Figure 4 shows the results that correspond to the current refurbishing scenario with 75 percent per weight of modules reused. This scenario show an economic gain of 143.9 € and an environmental impact gain of 13.42 percent. Even though these are attractive economic and environmental gains, the customer conditions for quality and upgradeability have still not been achieved. As a result, only a small number of the recovered products were refurbished. The company was afraid of losing market shares due to the uncertain quality and value obsolescence of the refurbished products.

The GCH could not be completed because some data were unavailable from the firm managers. This lack of data is normal and reflects the uncertainties about the reverse SC and its impact on the product and the forward SC designs. Most companies interested in remanufacturing their EOL products are struggling with similar uncertainties. During the interviews, we noticed that identifying and reducing these uncertainties, or the "constraining points," as managers call them, is a major obstacle to be addressed before the company invests in remanufacturing. With the help of the GCH, we detected several constraining points:

- Opposition of the marketing department due to lack of knowledge about how remanufactured product sales will affect new products sales (market cannibalisation)
- Opposition of the marketing department due to lack of knowledge about the reliability and the performance of the reused modules
- Opposition of the market regulator due to lack of an efficient traceability system to detect already-reused modules inside a recovered product
- Failure of the customer take-back contract to take into account the lifetime of the reusable modules
- The impact of reused modules on new modules supply pricing
- The lack of knowledge on upgradeability of the product.

The first results obtained by GCH methodology gave the decision-makers a global view of the parameters needed in the reverse SC design and how they interact. The next stage of the methodology is to collect more information on the missing parameters in the scenario construction through additional interviews and further literature reviews. Even though it is difficult to assess parameters such as market cannibalization or the impact of remanufacturing on the forward supply chain cost, we believe that the viability of the reverse SC depends on how realistic the assessments of such parameters are.

	Second customer needs							
	Economic cost : less or equal to the new product cost	**Value €**	**Environmental impact :** less or equal to the new product impact	**Value pt**	**Quality :** equal to the new product quality	**Value**	**Upgradeability:** equal to the actual new product technology level	**Value**
product	***Reprocessing technics* [1] :**		***Reprocessing techniques :***		***Reprocessing***		Upgradeability cycle	4 years
	Disassembly techniques added to the product	0	Disassembly techniques added to the product	0	Disassembly complexity level	medium	Mechanical components technology clockspeed	7 years
	Cleaning techniques added to the product	0	Cleaning techniques added to the product	0	Cleaning complexity level	low	Electronic components technology clockspeed	2 years
	Inspection techniques added to the product	0	Inspection techniques added to the product	0	Inspection complexity level	medium	Complete product design cycle	5 years
	Traceability techniques added to the product	0	Traceability techniques added to the product	0	Reassembly complexity level	medium		
	Durability:		***Durability:***		***Durability:***			
	Components with high durability [2]	0	Components with high durability [4]	0	Max durability of reusable modules	not evaluated		
	Recovery rate		***Recovery rate***		Min durability of reusable modules	not evaluated		
	Non-reusable modules	180	Non-reusable modules	22,7	Reliability of reused modules	not evaluated		
	Upgradeability:		***Upgradeability:***		***Recovery rate***			
	Upgradeable modules [3]	0	Upgradeable modules [5]	0	Recovery rate : remanufacturing	75%		
					Recovery rate : recycling	20%		
					Recovery rate : landfill	5%		
Forward Supply chain	***Suppliers integration* [6] :**		***Suppliers integration :***		***Suppliers integration :***		***Suppliers integration :***	
	Supply cost increases due to remanufacturing	0		0				
	Supply contract duration	0		0	Supply contract duration	2 years	Supply dynamics :suppliers selection frequency	2 years
	Profit share	0		0				
	Manufacturer: Alpha		***Manufacturer: Alpha***		***Manufacturer: Alpha***		***Manufacturer: Alpha***	
	Manufacturing cost increases due to remanufacturing consideration	0	Manufacturing impact increases due to remanufacturing consideration	0			Manufacturing process clockspeed	10 years
	Communication with RSC actors	1,5		0	Communication with RSC actors	ok	Supply chain clookspeed : from integral to modular supply chain	15 years
	Traceability system	0		0	Information technology	mail, phone	Outsourcing	medium
				0	Traceability	barcode		
	Customer		***Customer***		***Customer***		***Customer***	
	Lease contract cost increase due to remanufacturing	0			Lease contract duration	4 years	Lease contract duration	4 years
	Market Cannibalization	0						
Reverse supply chain	***Supplier (Reverse logistics process)***		***Reverse logistics (Supplier)***		***Reverse logistics (Supplier)***		***Reverse logistics (Supplier)***	
	Tack-back contract	0			Continuous supply	contract	Supply dynamics: loss and gain of suppliers	stagnant
	Acquisition price	35			Delivery lead time to remanufacturer	2 month		
	Transportation toward tack-back centers	0	Transportation toward tack-back centers	1,23	Cores transportation method	car		
	Tack-back centers (consolidation)	0,24	Tack-back centers (consolidation)	0	Number of tack-back centers	25		
	Transportation toward remanufacturing center	2,5	Transportation toward remanufacturing center	0,74	Transportation	batch, lorry		
	Remanufacturer: alpha		***Remanufacturer: alpha***		***Remanufacturer: alpha***		***Remanufacturer: alpha***	
	Center of remanufacturing	0	Center of remanufacturing	0	rate of product returns remanufactured	8%	Remanufacturing process upgrading	5 years
	Warehousing	0,75	Warehousing	0	Delivery lead time to customer	more than new product	remanufactured product upgradeability	not considered
	Remanufacturing process equipments	10	Remanufacturing process equipments	4	Remanufacturing process quality	medium		
	Remanufacturing labor	21	Remanufacturing labor	0	Labor qualification	medium		
	Remanufacturing process upgrading	3	Remanufacturing process upgrading	0	Remanufacturing planning	remanufacture to order		
	Traceability system	0	Traceability system	0	Traceability system	barcode		
	Transportation toward recycling center	0,11	Transportation toward recycling center	0,02	Traceability level	product		
	Recycling	2	Recycling	-1,11	customer guarantee	not delivered		
total	***Remanufactured product cost***	256,1	***Remanufactured product impact***	27,58	***Remanufactured product quality***		***Remanufactured product upgradeability***	
fixed limits	New product cost in customer market	400	New product impact manufactured with recovered materials : WEEE legislation recovery rate	41	New product quality		New product technology level	
gains		143,90 €		13,42 pt		not reached		not reached

the house of global cycle sheet

1- additional cost due to the techniques added to the product to support remanufacturing
2- difference in price between the ordinary material and high durability material
3- cost of the new components added to the upgradeable modules
4- difference in impact between the ordinary material and high durability material
5- impact of the new components added to the upgradeable modules
6- supplier integration is needed to insure supplier participation to the firm remanufacturing strategy

Figure 4: Alpha's Global Cycle House

5 CONCLUSION

Pareto-optimal solutions, according to many scholars, may be far inferior to the global best solution. In the same way, we claim that an economically and environmentally viable reverse SC requires coordination of product, forward SC and reverse SC design decisions as an essential factor.

While this idea could be conceptually powerful, relatively little is known about how to actually coordinate these three design dimensions. This paper provides some theoretical foundations to this concept. The proposed methodology and its application to the Alpha case study show interactions among the three design parameters. Decision-makers must thoroughly understand these interactions before they invest in a structured reverse SC design and implementation.

More research is needed to understand how coordinating the three design dimensions affect reverse SC viability in positive way. Future investigations could address these questions:

- Is satisfying the remanufactured product buyer's conditions sufficient to convince a company to remanufacture its EOL products?
- How does reverse supply chain implementation affect the existing forward supply chain?
- How can factors such as market cannibalisation be evaluated and integrated into the total cost of a remanufactured product?
- How have companies like XEROX modified the design of their products and forward SCs to take remanufacturing into account?

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