Creating value from returns

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The impact of product life cycle management on circular supply chains – and reverse

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Abstract – In this paper we study how value should be regained from returns. We define typical returns and their matching optimal reverse chains. We argue that integration with the forward chain provides the best opportunities, in particular when based on modular reuse. Real closed loop supply chains based on modular reuse however require closing goods flows, but also informational and market loops. To this end the interface between circular supply chain management and product life cycle management is essential. The findings are supported by many case examples and a more extensive case study at Auto Recycling Nederland.

Key words - reverse logistics, supply chain management, circular supply chains, product life cycle management, propositions, value regain

1. Introduction

Business Logistics Management has gone through severe changes over the last few decades. Customers have become more and more demanding and increased transparency, e.g. through internet sales, is shifting the balance of power more in their favour and gives them the opportunity to actively configure the final product. The focus today is on creating value through personalised and individualised offerings to customers, while at the same time 'traditional' requirements such as high quality and low cost remain important. The market trend to mass customisation has created a variety of product options that a company must offer. Moreover, businesses are expanding into international markets, requiring the ability to manage manufacturing and distribution on a global basis. Cross company concepts, referred to as Supply Chain Management, are necessary to meet these increasing demands.

Supply Chain Management is defined by CLM as "the integration of key business processes from end user through original suppliers that provides products, services and information that adds value for customers and other stakeholders" (Stock and Lambert, 2000). Actual realisation of SCM occurs by implementing concepts, such as Efficient Consumer Response (ECR), Continuous Replenishment, Collaborative Planning, Vendor Managed Inventory and so on.

Yet another fundamental change is taking place. Traditionally aiming at the optimisation of customer service and cost *until* the point of sales, Business Logistics practitioners currently experience a paradigm shift towards 'cradle to grave' approaches for a number of reasons:

1. End of life take-back responsibilities. Due to environmental concerns, legislators increasingly hold original supply chain players responsible for the collection and recovery of end-of-life items. This is often referred to as Extended Producer Responsibility or EPR (Lifset and Lombardi, 1997).
2. Increased claims and recalls. Both legislators and consumer organisations enforce consumer right to return because of malfunction or customer dissatisfaction. This leads to increased returns under warranty, recall or because of displeased consumers. The latter category is gaining importance: according to Fidler (2000) 70% of consumer goods returned to the shop are non-defective, but are returned for other reasons (lower price elsewhere, over-advertising, do not know how to operate the thing, etc.).
3. Shortening economic life cycles. Due to rapid technology improvements, product replacements and system upgrades increase. Due to more actions, an increased number of products are obsolete before even being sold. Both result in increased returns.

4. Increased catalogue sales (mail order/e-commerce). During the 1999 holiday season, 25% of all online purchases were returned shortly after sales (Stock, 2001).
5. Increased function selling. Profit is made more and more in supplies and service rather than in direct sales. For example automotive industry sells mobility rather than cars. A popular example is the one of a middle class car of EURO 20.000 that costs over EURO 100.000 when sold bit-by-bit in (spare) parts. In B2B, product lease and service level agreements increasingly force the OEM to guarantee availability of the installed base. Similarly, in B2C, extended warranty policies are implemented. As a consequence, there will be increased returns of defect or end-of-lease products and parts, and on the other hand increased demand for (repaired) spare parts and exchange products.
6. Increased 'recycled' content in new products. Both legislators and customers increasingly demand that new products are partly manufactured out of recovered components and materials. As a positive spin-off, this creates new markets for returned items. An example of this is the paper and pulp industry (Bloemhof, 1996).

The 'cradle to grave' paradigm effectuated through product life cycle management (PLCm). In our definition, PLCm is the process of optimising service, cost and environmental performance of a product over its full life cycle. Key issues include product design for recovery, re-engineering, product data management, installed base support and evaluating (end-of) life scenarios. PLCm is supported by methodologies such as life cycle assessment (LCA) and life cycle costing (LCC). Note that 'product' also refers to components, packages, carriers, refillable units and so on. As a consequence, supply chains are extended into circular supply chains. The relationship between PLCm and CSCm is reflected in Figure 1.

The authors define circular supply chain management as "the integration of business processes that create additional value for all original and new players[1] in the supply chain through closing goods flows". (Additional) value creation refers to both traditional supply chain objectives, customer satisfaction and cost reduction, as well as environmental goals. The forward chain is extended by a Reverse Chain incorporating key

[1] Actors in the return channel

business processes such as product acquisition and collection, asset recovery, secondary sales and re-distribution as well as related information and financial processing. The circular supply chain covers the combined forward and reverse supply chain. It includes both open-loop and closed-loop supply chains, hence closing goods flows can also occur by reuse in alternative supply chains.

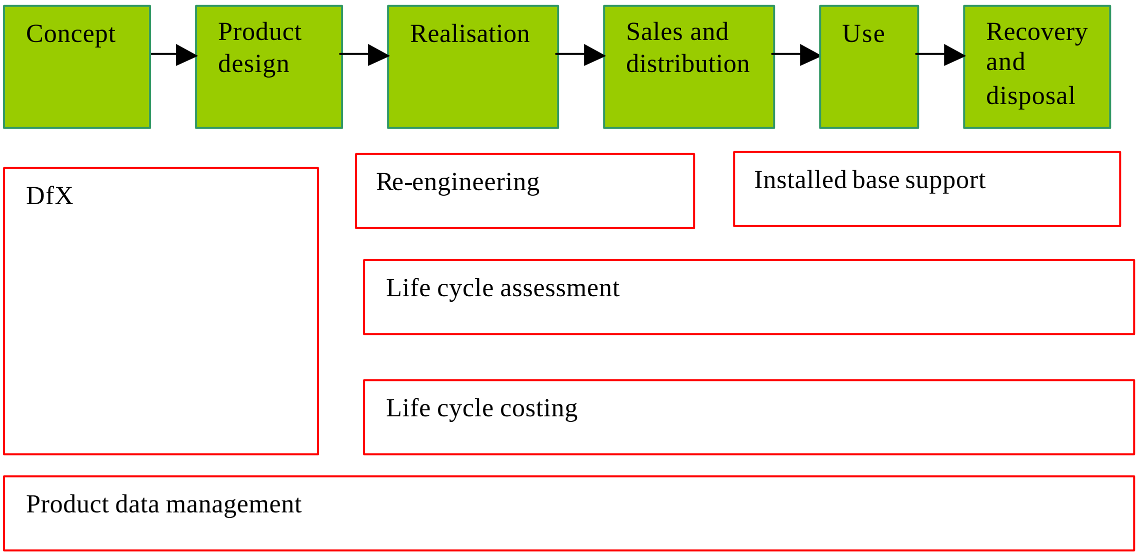

Figure 1: Product Life Cycle mgt. and (Circular) Supply Chain mgt.

(adapted from Westkaemper and Osten, 1999)

Circular supply chains add complexity to overall supply chain management: traditional objectives of customer service and cost are extended by environmental concerns and the scope is extended by return processes. This leads to a number of new coordination issues, including cross-border waste transportation, more complex trade-offs in supply chain objectives, increased (perceived) conflicts of interest amongst actors, micro internalisation of macro externalities and so on. The intrinsic complexity may be a reason why many companies do not bother to regain value from returns. Yet, there is sufficient evidence that applying PLCm and CSCm strengthens a companies' competitiveness. This is already discovered by pioneers such as Kodak, Oce Technologies, Mercedes Benz, Xerox, ReCellullar, Philips, Volkswagen, IBM, Estee Lauder, Genco, and many others.

In this paper we address three major research questions in this context, focusing on the maximal value regain of returns, where value refers to cost, customer service and environmental impact.

- Which reverse supply chain for which return?
    a. Which typical returns and typical reverse supply chains can be distinguished?
    b. Which typical reverse chain is optimal for which typical return?
    c. What are key variables in the reverse logistics concept?
- Can performance be improved by integration with the forward chain?
    a. Which SC concepts offer particular opportunities for integration?
    b. Which value is created at which point in the full CSC?
    c. What are key variables in the integration?
- Can performance be improved by managing the interface of PLCm and CSCm?
    a. What is the nature of the relationship between CSCm and PLCm?
    b. Which constraints are encountered in CSC optimisation?
    c. What are critical variables on the interface?

Our methodology is as follows. The first part contains a normative description of how CSCs should be organised. We do so by developing a classification approach, based an extensive literature search, with many case examples. In the second part we use an explorative approach. A case study is carried out at Auto Recycling Nederland (ARN), the national car recycler in the Netherlands. We apply the first part of the paper, and find that this considerably increases value creation from returns but indeed the full potential is not reached. The case study is used to explore which PLCm factors exactly relax CSC constraints. This leads to the formulation of three propositions.

The set up of the paper is as follows. Section 2 discusses CSC optimisation. Section 3 describes the ARN case, the CSC optimisation based on developed theory and constraints experienced. Section 4 discusses PLCm aspects for relaxing these constraints. Section 5 contains a conclusion and an outlook.

2. Circular Supply Chains

2.1 Returns defined

This paper deals with optimising additional value creation through closing goods flows Therefore it is logical to first define the goods involved, hence the different types of returns (based on Fleischmann (2000) and De Brito et al. (2002)):

- Commercial returns are defined as all products returned from the market for which there is an immediate demand at some other market location or segment. Causes of return can be customer dissatisfaction, catalogue sales, overstocking at retailers, promotional actions etc. Commercial returns occur in the sales phase or shortly after.
- End-of-use returns are all products and components returned which -after some period of operations- are of no longer use to the original owner, but for which new customers can be found. Reasons for return include end-of-season, end-of-lease, trade-in and product replacements. End-of-use returns generally require some processing and/or upgrade before it enters either the same or some alternative market. An important subdivision has to be made between goods that can be transformed into new products, thereby loosing their identity, and tradeable products that can only be repaired or refurbished, and need to be sold at alternative or service markets.
- Repairables concern defects and suspect components (modules/parts) from field (exchange) repair activities or products under warranty or a recall. Under all circumstances the customer is entitled to have the same or a similar product (function) back.
- Reusable carriers, i.e. containers or pallets. Carriers are universal and used for transportation and storage. Their returns are related to distribution activities rather than consumption.
- Refillable units. Typical of these units is that they are not the product, but contain the actual product. Examples include toner cartridges, reusable cameras and beer bottles. Returns result from exchanges (toner) or independent returns (camera after removal of the film). A refillable unit is related to consumption or use.
- End-of-life returns are all items of no longer use to anyone, which need to be processed due to contractual or legislative take back obligations. These returns are often worn out and compulsory processed according to legislative prescriptions.

In Table 1, six recovery options are given at a conceptual level, namely direct reuse, repair, refurbishment, remanufacturing, cannibalisation and recycling, based on Thierry et al. (1995).

Table 1: Outline of recovery options

Options	Operations	Resulting output
direct reuse	check on damage and clean	as is, e.g. for refill
repair	restore product to working order, some component repaired or replaced	original product
refurbishing	inspect and upgrade critical modules, some modules repaired or replaced by upgrades	original product in upgraded version
remanufacturing	manufacture new products partly from old components	new product
cannibalisation	selective retrieval of components	some parts, modules reused, others scrapped
scrap	shred, sort, recycle and dispose of	materials and residual waste

Figure 2 represents the application of the recovery options in the multi-loop product life cycle. Goods flows may over time follow several loops of reuse through different levels of recovery and serve different purposes. Note that a particular item can be a different kind of return at different stages of its life cycle.

Figure 2 (a/b) about here

Theoretically, there are three life cycles on the product level, of which two are recovery loops. In a fourth loop, the products are cannibalised on parts for reuse and the remainder is scrapped (a combination of recycling and disposal). It is possible to skip a loop or to repeat one. Note that design information is passed on to subsequent life cycles and user related information is fed back to the design phase.

2.2 Reverse Chains

Typically reverse supply chains comprehend the following five groups of activities, which are linked by intermediate transportation (Fleischmann et al., 2000):

- Collection: all activities rendering used items (product, component or material) available and physically moving them to some point for further treatment. This may involve product acquisition, transportation and storage.
- Inspection/separation: results in splitting the flow for various recovery and disposal options. This may involve testing, disassembly, shredding, testing, sorting and storage.
- Re-processing: reusable flows undergo the actual transformation of a used item into a reusable item of some kind. Depending on the recovery option chosen, this comprehends various activities such as disassembly, shredding, repair, replacements etc. Various recovery options are reflected in Figure 2.

- Disposal: the non-reusable flows are disposed of to incinerators and landfills.
- Re-distribution: directing reusable items to a market to new markets, and physically moving them to potential new users. This involves sales activities, transportation and storage.

Ideally circular supply chains enhance the provision of better products, services and information than originally accomplished by the forward supply chain on its own at lower cost and reduced environmental impact. Table 2 summarises business benefits as described by e.g. Thierry et al. (1995), Fidler (2000), Stock et al. (1998) and Rogers and Tibben-Lembke (1998). To create these business benefits however, CSC configurations may be quite different. As part of that, the reverse supply chain turns out to be quite different per type of return because their way of value creation is totally different.

Table 2: Summary of business benefits of circular supply chains

Service/market	Cost	Environmental/safety
return service improves customer satisfaction	reduced liability risk	reduced environmental impact
reduced R&D time-time to market	regain value of materials and components	compliance with legislation
increased spare parts availability	regain value of labour	more reliable recalls of defect products
timely retrofit through early take back	avoid disposal costs	
improved product quality through re-engineering	reduced obsolescence risk through timely return	
pro-active repairs	less new production spare parts	
Green image	returns reduction	

2.3 Returns and their typical Reverse Chains

Excellent studies on reverse supply chains' typologies have been presented by Fleischmann et al. (2000), Bloemhof et al. (1999) and Guide and Van Wassenhove (2002). Table 3 and 4 summarise their findings. Table 3 describes product-market characteristics for the typical returns defined earlier. Essentially, the reverse chain needs to be adapted to product-market characteristics. Each return type has its own type of reverse supply chain: reverse distribution, trading-repair, hybrid (re-) manufacturing, bulk recycling, cyclic replenishment, service-repair and the carrousel. Next we present some representative case examples for each type.

Table 3: Product-market characteristics for 7 typical returns (summary of literature)

Product characteristics	Commercial	EOU trade-able	EOU-transformable	EOL	Refillable units	Reuse carriers	Repairables
Remaining lifetime	high	moderate	high for some components	low	high	high	moderate-high
Obsolescence risk	high	high	moderate	low	Low	low	high
Take back Legislation	no	no	no	EPR	No	no	warranty
Product complexity	low-high	low	high	low-high	Low	low	high
Most common in:	consumer market	consumer market	B2B, capital goods	all	all	B2B	all
Recovery option	reuse repair	refurbish repair	remanufacturing cannibalise	cannibalise recycle	reuse Repair	reuse repair	repair refurbish
Market characteristics	Commercial	EOU trade-able	EOU-transformable	EOL	Refillable units	Reuse carriers	Repairables
Return rate as % of sales	moderate	moderate	high	high	high	high	moderate
Return uncertainty	low	high	moderate	moderate	low	low	moderate
Buy back price	crediting	market	end-of-lease	none	none	none	crediting
Secondary demand	high	moderate-high	moderate-high	low	high	high	moderate-high
Secondary price/value	high	moderate	high	low	moderate	moderate	high
Compete with primary market?	yes	no, second hand markets	yes	no, material markets	yes	yes	yes
Market span	national	regional/ worldwide	regional	national	national/ regional	regional/ worldwide	regional

Table 4: Matching Reverse Chain with return and design criteria(summary of literature)

Return type	Commercial	EOU trade-able	EOU-transformable	EOL	Refillable units	Reuse carriers	Repairables
Type of Reverse Chain	reverse distribution	trade-repair	hybrid-(re)man	bulk recycling	cyclic replenishment	carroussel	service repair
Director	distributor	Spec. firm / broker	OEM	alliance/ LSPs	OEM	3rd party	OEM/LSP
Main driver	economic value regain	economic value regain	economic value regain	recovery targets	mixed	cost and retailer space	customer/ economic value
Collective system	n	n	n	y	n	y	n
Kind of loop	closed	open	closed	open	closed	closed	closed
(de-) centralised	decentral	decentral	central	central	central	decentral	central
Control focus	obso-lesence	consolida-tion	yield/quality	Economies of scale	economies of scale	availability	obsolescence
Control direction	push-pull	pull	push-pull	push	push-pull	push-pull	push-pull
Lead time	days-weeks	days-weeks	weeks-months	months	weeks	weeks	weeks
Acquisition	cust.return	active buy	cust.return	advertise	cust.return	last user	defect
Collection	LSP	LSP	LSP	Mun./ret.	Retailer	LSP	LSP
Testing/sorting	DC	Spec. firm	OEM	Spec.firm	LSP	Depot	Spec.firm
Recovery	DC	Spec. firm	OEM	Spec.firm	OEM	Depot	Spec.firm
Sales/ redistribution	Forward channel	Alternative cascading markets/lsp	Forward channel	Material market/ lsp	Forward channel	Forward channel	Forward channel
Common IT used	WMS	internet	ERP	?	?	Tracking & tracing	?

(Caldwell, 1999) presents a case study on Estee Lauder regarding commercial returns of cosmetics products. Their reverse logistics program comprehended streamlining of reverse logistics processes including returns authorisation, adapting the WMS and developing reuse markets (company stores). The time based value of these returns makes responsiveness essential, particularly in collection this may lead to high cost. As with most return channels, collection is carried out separately, although often by the same lsp. Sectors with large volumes of commercial returns are mail order and e-commerce.

(Guide and Van Wassenhove, 2002) describe ReCellullar, a company that collects, recovers and sells for second hand mobile phones. The company operates a complex trade-repair CSC in a global market, where product acquisition and demand management are critical due to high volatility of markets and lacking technological standards. Active buy back and air transportation create a responsive CSC, in which consolidation is trade off against speed. The use of internet plays an important role for ReCellullar, which is typical for many trade-repair systems. Kokkinaki et al. (2001) describe three E-marketplace business models and examples, including Ebay.com. Once supply and demand are matched, quality issues are difficult to be dealt with on distance and testing often needs to be done after final collection, thus imposing a risk to the buyer.

Hybrid Manufacturing is particularly found in the copier industry, e.g. at Oce Technologies (Krikke et al., 1999). The key in these CSCs is dual sourcing which allows OEMs to manufacture identical machines both brand new and partly from secondary components, depending on availability of returns. Remanufactured products are sold as new. Yield of returns and quality (perception) of remanufactured products make testing and recovery the critical processes. Next to Oce, e.g. Xerox applies similar concepts.

De Koster et al. (2002) describe a collective recycling system of Dutch consumer electronics OEMs/importers. Unlike the above this system is driven by EU legislation based on Extended Producer Responsibility. The OEMs outsource the recycling and the overall deficit is charged to the consumer when buying a new product. The system focuses on carrying out the EU directive, which implies extensive measurements and reporting of material balances. For the processors, large volumes are important in view of cost effectiveness. Often collection proves to be hard, since there is a time long gap between sales and return. Products may have changed owners many times and the final user does not have a real economic incentive to hand in the product. Also finding markets for the secondary materials proves to be difficult. Similar concepts are applied to –amongst others- end-of-life vehicles, packaging, batteries, tyres and construction waste throughout the European Union and in some Asian countries.

Guide and Van Wassenhove (2002) describe the cyclic replenishment of refillable toner cartridges at Xerox. When buying a new cartridge they can return the cartridge via an enclosed prepaid postage label or drop it off at the retailer in an eco-box. Collected cartridges are refilled at the OEM facility and distributed via the regular forward channels. Another example is Kodak, which refills 'single use' cameras with new films. The fact that return and reuse is connected to the use of the product contained in the refillable unit makes this a relatively simple CSC.

Kroon and Vrijens (1995) report on a case study concerning small collapsible plastic containers that can be rented. A logistics service provider is responsible for all logistics activities, i.e., storage and maintenance, delivery, and collection of empty containers. When they are not used, containers are stored in depots. When needed for transportation they are shipped to the company that needs them. Moreover, after use empty containers are collected from the recipient and stored until it is needed again. Therefore we call this a carroussel system. It is not the most difficult CSC, but the balancing of supply and demand may be difficult at times.

Krikke et al. (2002) describe the Honeywell case, who used a reverse distribution system for service repairs. This led to long lead-times and high obsolescence rates. After careful analysis it was decided that the CSC was to be changed into a service-repair chain as described in Table 4, using a carrier for collection and transportation. In this chain, one needs to be quick, since value is often time based. Also quality (perception) is a difficult issue here.

Figure 3 depicts the basic structures of these typical reverse supply chains. De Brito et al. (2002) present an overview of over 60 case studies and discuss the logistics concepts of these cases. Note that 5 out of 7 are real closed loops, and thereby automatically we obtain a CSC, an integrated forward and reverse chain.

Figure 3 about here.

Table 4 summarises characteristics and design criteria of the reverse chain developed from the case studies described in the literature cited. The first three lines describe the type of reverse chain, goals set and the director. The next 3 rows concern network design, then 8 rows of control criteria and the final row concerns common IT systems geared for CSCs (note that we ignore propriety systems).

2.4 Circular chains: the importance of the forward chain

This paper focuses on value regain, where value can be interpreted from an economic, customer service and environmental perspective. Guide and Van Wassenhove (2002) report on several cases of successful closed loops for economic regain. Krikke et al. (2001) report on both economic and environmental advantages in refrigerators recovery. It appears that particularly component or product reuse is beneficial since much (forward')added value is preserved, not only materials but also labour and energy etc. This is referred to as 'the . Now the idea is to strengthen the closed loop effect by piggy backing on the in themselves autonomous supply chain concepts described above. Here we point out new supply chain concepts that create new opportunities for circular supply chain optimisation:

- Mass Customisation and postponement. To enable concepts such as mass customisation and postponement, which refers to building customised products by mass produced components, modules are produced by mass-production and customised on demand in final assembly. A wide range of products is offered based on a relatively small number of modules. For non-assembly products, it is increasingly tried to reduce the base of materials used. This links to the principle of source reduction as described by Marien (1998). Standardisation of e.g. EURO pallets is an example of CSC-favourable developments in carriers.
- Monitoring systems installed for logistics and maintenance. Monitoring systems are often used to enable service engineers to detect failures at an early stage. Reduced cost and increased capacity of wireless transactions via cell phone networks enables remote monitoring, not only of capital intensive goods but also of somewhat cheaper consumer goods, which in turn enables increased control over the returns process. Other useful technologies include POS registration, 2D bar-coding, electronic marketplaces and RFID. Tracking and tracing for logistics purposed has great potential for easing collection.
- Advanced planning. Through IT, an increased number of parameters can be monitored, resulting in lots of data but not necessarily information. Sophisticated mathematics can help decision makers to filter relevant

information and take appropriate action. APSs may also assist in optimising circular supply chains. The REVLOG project has produced a number of optimisation and simulation models for CSCm (REVLOG).

- E-commerce is of relevance in many ways. It causes returns due to bad fulfilment, it offers product acquisition and reselling opportunities but it can also reduce returns. Caldwell (1999) reports on a Dell, that reduced the amount of returns from Web orders to a level below that of phone ordering through adding a configuration feature to its website. Lately, many companies are setting up call centers and replace manuals by CD-roms to reduce the return volumes.
- Green new business models. The use of 'recycled stuff' should be promoted rather than hidden. For example, some car insurance companies offer green policies, through which a damaged car is repaired with parts cannibalised from dismantled wrecks. Xerox leases a green line of copiers, providing a lower cost per copy. Faith in quality will be a major obstacle, the trend towards 'function selling' may be helpful. Suppliers need to be selected on sustainability and compensated for the potential loss of business, e.g. through outsourcing repairs to them and the supplier base might be reduced. Companies themselves must also change their internal mindset. Fidler (2000) concludes that most consumers who return a product leave the shop with a credit, no product but still a need for it. Sales staff needs to be trained: do not just take back the product, ask for the reason and try to re-fulfil the demand. Management should view recovery as an alternative source of procurement and subassembly manufacturing. Internal performance measures and balanced-scorecards need to be adjusted.

Here we end our discussion on how CSCs should be organised. The insights were developed from extensive review of case based literature. Next we apply lessons learned in an automotive case.

3. Auto Recycling Nederland

In order to execute the EU Directive on Extended Producer Responsibility, all car importers in The Netherlands including Mercedes Benz, Opel, Volkswagen, and the Japanese trademarks, have jointly set up ARN, a collective organization for coordinating the recycling of end-of-life vehicles (ELVs). Existing ELV-dismantlers, collection companies and recycling companies are carrying out the work for ARN on a commercial basis and recycle over 275,000 vehicles yearly. The chain deficit is financed by charging the customer a fee at the point of sales, so the final user hands in his car 'for free'. Reusable parts are dismantled, after which the remaining wreck is recycled on the material level. An overall 86% recovery score (measured by vehicle weight) is achieved, which exceeds the targets of the current EU Directive. Many other EU states take over this role model. Now let us take a look at reverse chains of ARN.

3.1 CSC optimisation at ARN and beyond

The first part of the paper boils down to:

- Value creation by closing goods flows is realised best when returns are handled by their matching reverse chain.
- Value creation by closing goods flows is improved when integrating forward and reverse chain in to closed loops thereby connecting to forward supply chain concepts.

In fact, ARN does not manage a reverse chain, but a network of reverse chains, most of which are 'bulk recycling'. Le Blanc et al. (2002) describe a recently redesigned chain for the recycling and reuse of LPG-tanks using Advanced Planning techniques. Before the redesign of the chain most LPG-tanks were not transferred to the degassing company but traded by the ELV dismantlers. This causes a high safety risk, but the high economic value of LPG-tanks made ELV-dismantlers to do this. In the redesign, the system is made more attractive for ELV-dismantlers; i.e. fast and free collection of non-degassed LPG-tanks and quick return after degassing. They can then be traded safely. The degassing company is compensated by ARN. As a consequence, the logistics system changed from on call collection of full storage racks to a periodic collection system that collects all available LPG-tanks every 4 weeks and returns the degassed tanks that were collected in the previous period. This system is less cost efficient but adds value in the form of safety. After the redesign of the chain, LPG-tanks were considered as an EOU tradable instead of EOL return and the reverse chain was adapted according to Table 4

With regards to the forward chain, the value of used and returned products as a source of spare parts is becoming widely recognized. A few years ago insurance companies introduced so-called “green” insurance policies. The idea behind this concept is that total loss cars often are damaged at just one side so that the other side is a good source for parts cannibalisation. Parts coming from ARN-partners are used to feed the system. Integrating forward and reverse chain brings additional value by offering choice to the customer for repair with ‘green’ or new parts and reducing total cost of ownership. Also, the total reverse chain deficit is reduced by reuse of components.

OEMs (the suppliers of new parts) more and more see the opportunities of used parts and are contracting ELV-dismantlers. Driesch et al. (1998) give an example of the reuse of engines at Mercedes-Benz. The customer with a worn engine in his car is offered the service in which a worn engine can be replaced by an overhauled engine with manufacturing guarantee. The worn engine is sent to a recovery center for overhauling. The engines that cannot be overhauled are cannibalised for overhauling parts or for material recycling. The refurbished engines are popular with taxi drivers because of the higher reliability. Mercedes Benz at the time reduced the load on her engine (forward) manufacturing capacity. Also, MB has reduced failure rates and reduced the use of materials in the forward chain by learning from returns.

The ARN case suggests that closed loop supply chains has the greatest value regain potential through component reuse. Although there is a lively trade in second hand cars this seems not to be in the best interest of the OEMs, since it potentially cannibalises primary markets and counters innovation. Few component based closed loops are applied with promising results, but applications are limited due to a number of constraints in optimising these CSCs. These are discussed in the next subsection.

3.2 Constraints in CSC optimisation and initiatives

In automotive industry, integration of return in the forward chain is strongly affected by several developments, in particular the changing material composition of cars, extreme safety standards, massive R&D cost, and a ballooning of product options based on standard components (mass customisation).

An interesting case is the recapping of tires. About 10% of the tires satisfy the requirements for recapping and get a new life as a tire since age and quality put restrictions on the recapping opportunities. The recapping of tires was profitable business for a long time, because sales price for reuse was around EURO 60 per tyre and material recycling brought revenues of EURO 1 per tyre. However competition from Eastern Europe reduced the prices of new tires have considerably and the market for recapped tires is under pressure. One of the issues is quality perception, people often fear to drive unsafe. Lowering secondary prices may actually feed this feeling.

More in general, the increased use of aluminium, composite fibres and electronics reduces possible recycling yields. Although manufacturers are considering easy disassembly techniques for maintenance and end-of-life purposes, R&D has been primarily focused on weight and hence energy reduction rather than recyclability. Limited resources make prioritising necessary. Mass customisation has created a lot of mostly irreversible options and although specialised information systems have been set up, it appears to be difficult to (timely) match supply and demand. Despite modularity, many good parts are shredded. E-commerce might provide better consolidation opportunities, which in turn asks for good product information. ARN has its own research center in which it dismantles a number of cars itself to the last mount, collecting product data for which the information currently is not available. It is important to gather data about the 20% of models that will be 80% of the wrecks in the near future. Also, ARN makes forecasts on the installed base covering a horizon of 15 years. The forecast for the first years (1-5) of the horizon are used for estimating the needed recycling capacity and effectuating an efficient logistic chain. As of early 2000, EU legislation is forcing the automotive industry to provide a recycling passport containing crucial data within 6 months after introduction of a new model on the market (EU-directive 2000/53/EG). The introduction of the recycling passport will ease the collection of static product data, but user related dynamic data will still be hard to get. Remote technology might offer opportunities to relax these limitations. Condition monitoring is widely used in automotive industry for maintenance purposes but not applied to CSCs. Lack of reliable information systems also limits the use of APS.

In conclusion, ARN and its partners experience limitations in closing loops in the physical sense, but as important (!) also in closing loops from an informational and market point of view. Moreover, there is a long lasting discussion on how important the end-of-life phase is for the environment. Many argue that fuel consumption is far more important, reason why OEMs have focused on weight reduction and new engine technology rather than recovery aspects. Next, we develop a framework for investigating these issues and increasing CSC optimisation (by closed loops) through product life cycle management (PLCm). Since there is little empirical material, this part of the paper is of more explorative nature.

4. And reverse: improving CSCm potential by PLCm

In section 4.1 to 4.5 we discuss the various interface variables between PLCM and CSCs in the different subareas of PLCm. We finish the analysis by formulating propositions.

4.1 Product Design for X (DfX)

Mass customisation and postponement requires modular product designs that allow cross compatibility of components to configure various product types. The overall functionality of a product is decomposed into subfunctions, which are to be provided by individual components. The specification of the interface between the components to ensure that these individual subfunctions act coherently. The specification of the interface is critical: flexible product designs allow you to substitute components without having to make adjustments in other components (Sanchez, 1999). We distinguish a number of principles.

The first is the most obvious, components should be 'reusable' at large: disassembly, repair, recycling and so on should be enabled. For instance, new construction techniques enable that a returned product once exposed to the correct temperature range, will be triggered to automatic disassembly. Second, in order to create secondary demand in the forward chain, cross generation compatibility is important. Customers have an installed base that generally have longer life cycles than the replacement cycles at the OEM. For example, for most PCs it is easy to replace an older hard disk with a new one, because the interfaces between the hard disk and the rest of the computer have been defined well. Third, and in line with this, to regain as much value as possible, value separation is essential. This means that capital intensive parts, mechanical parts and technology advanced parts must be contained in separate modules, so when a product is returned the capital intensive, but technologically stable components can be separated easily to regain maximal value. The above refers to modularity in a downward sense: the product is built up

of modules. In the upward sense the item involved (e.g. refillable units, reusable containers) are a module in a higher level system, but the same remarks apply.
Much attention has been paid in the literature to DfX and source reduction with respect to material recycling. Although important, we believe that material recycling is not the prime key to value regain and hence to not go into detail. We refer to Marien (1998).

4.2 Re-engineering

Re-engineering in general involves the improvement of product quality and reducing the use of material and labour resources in the forward chain by learning from returns. Here, the value of returns, being the 'supply chain's mirror', lies in the learning curve as described by Driesch et al. (1998) for Mercedes Benz. It is important to carefully register returns using standardised coding for e.g. reason and channel of return, only detailed analysis provides the tools to reduce the returns volumes (Fidler, 2000). Giuntini and Andel (1995) report on a steel mill case, where through re-engineering material costs were reduced by 40% and MTBF was strongly improved. Original suppliers have to be involved in re-engineering of their subassemblies, thus improving overall system performance.
We like to pay attention to the reuse of design itself. In many sectors, including the automotive, the cost of research and development versus production is enormous, not only in terms of money, but also in time. Developing new products based on selectively upgraded components reduces time-to-market and generates tremendous savings on development costs and reduces design flaws. Thus, the product development process should incorporate the possibility of design reuse, independent of the fact whether or not physical reuse will be applied. Advanced CAD/CAM systems enable quick redesign of products as well as automated implementation of these designs into manufacturing systems. An issue related to this is the innovation paradox. Re-engineering stimulates incremental innovations by upgrades, however radical innovations may be obstructed by it.

4.3 Dynamic product data management (PDM)

The planning and control of circular supply chains depends, as with regular supply chains, strongly on the use of information. In Krikke et al. (2002) various forms of information technologies in CSCm are described. These systems often work independently and integration is lacking. The missing link can be provided by Product Data Management. PDM in general serves to maintain accurate data on complex products (many parts, variants, alternatives), record maintenance changes on a product during its lifecycle and disseminate product data at an intra-organisational or inter-organisational level. PDM improves the quality of data and reduces labour intensity, since it reduces the amount of manual data transfer of information in the chain. Exchange of consistent, reliable data makes for individual parties in the reverse chain exogenous variables more endogenous.

Klausner et al. (1998) report on a so-called green port (chip) implemented in Bosch power tools for EOL optimisation. Based on the monitoring of a few parameters during the products life time, a DSS is capable of classifying returned cores into 'reusable' and 'scrap'. Most applications are found in maintenance. Examples include early detection of technical failures, optimisation of fuel consumption and automated replenishment, often done remote via wireless connections. However, to the best of our knowledge there is no application of remote conditioning for asset recovery operations. Moreover, in order to ease collection, it is important to know the condition, but also the location of the returns in advance. As we already mentioned, many companies are able to monitor, track and trace product and packages in the forward chain, often using GIS or GPS, why not use them for the returns planning?

In case PDM is not well established or in case or extremely long life cycles, substitutes may involve the use of scan units. A scan unit is able to make an X-ray of returned goods and make a reliable estimate of product parameters otherwise monitored by PDM (de Jong and Dalmijn, 2002). Note that increased reusability also increases the danger of other parties taken over the remanufacturing business. Therefore some companies have inserted a chip in their product that contains a secret code, which is needed to reset and hence reuse the chip.

4.4 Installed base support

The installed base is defined as the total number of placed units of a particular product in the entire primary market or a product segment. Installed base management concerns the care of products during operations. It comprehends replenishment, maintenance repairs, overhaul, spare parts management, and system upgrades. The installed base is a source of information, but also a source of 'supplies'. Active product acquisition allows CSC optimisation, but requires incentive schemes for customers (crediting, deposits) to actual control the returns and have them returned in the proper manner. The installed base is also a secondary important market, for example in overhaul, upgrades or repair. This is becoming increasingly important because of the ever stronger increasing replacement and phase out rates at customers.

Traditionally, installed base support is looked at from a technical point of view. However, the installed base can also be monitored on more commercial parameters. For example, when a customer with a high volume copier only makes a few copies a week, there is a clear case of misfit. Early takeback and recustomisation by retrofit or product exchange might be an appropriate strategy. Moreover, one may offer additional support services such pro-active repair using PDM systems. Altogether, the customer should be made comfortable by the fact that the function of the product is ensured and monitored permanently. The quality perception issues might be eased by taken such an approach.

4.5 Supporting techniques: LCA and LCC

The two prime techniques used are life cycle analysis (LCA) and life cycle costing (LCC). Life cycle assessment (LCA) aims to measure the environmental impact associated with a product, generally of a dozen of environmental impacts, including energy use, waste volumes and toxiticity. From a reuse point of view it is important to know that reuse of components in real closed loops often saves a lot of energy and materials. However, this needs to be studied on a case- by-case basis, and sometimes open loops may be found to be better. Examples of (simplified) LCAs combined with an economic optimisation can be found in Bloemhof (1996) and Krikke et al. (2001).

With regards to economic models, life cycle costing considers the cost of product realisation, (multiple) operation and (multiple) recovery, eventually leading to a better economic result. A synonym often used is total cost of ownership. In SCM, Activity Based Costing is often presented as a means to fairly assign cost to activities and hence to identify opportunities for efficiency improvements. Goldsby (2001) shows how ABC was used to improve return channels for packaging. However, this study is limited to actual operations of one re-loop only. The analysis becomes substantially more complicated when one has to assess cost and revenues of multiple recovery loops that lie ahead in time. Nevertheless, when optimising CSCs, the decision process might be severely influenced if we can include the capitalised value of future recovery options. On a more strategic level, it is important to objectively measure the business potential of circular supply chains. Guide and Van Wassenhove (2000) describe how an EVA-based methodology can be used for these purposes, and they apply it to ReCellullars activities. Teunter and Van der Laan

(2001) show the severe impact of valuation methods on economic results. These methods are necessary to show that the (future) reuse can be economically profitable and that possible higher initial cost may actually be a good investment.

In most cases, LCA and LCC will consider the product life cycle as a whole and hence the entire circular supply chain. However, for specific purposes the scope might be reduced.

4.6 Propositions

Based on the analysis we formulate three propositions:

P1: Value creation from returns is best accomplished in closed loop supply chains based on modular reuse, where modular refers to components in a product or the product being a module of a larger system.

P2: Value creation not only involves closing physical flows, but also closing loops from an informational and market perspective.

P3: Value creation is only achieved in an optimal manner when integrally managing PLCm and CSC variables.

In the appendix we summarised our propositions in a framework that gives decision support for value creation through closing goods flows

5. Conclusions and outlook

The cradle to grave paradigm is here to stay. Inevitably companies will deal with it and better learn to make the best of it by adopting concepts such as Circular Supply Chains and Product Life Cycle Management. At the CSC level, our framework matches typical returns to typical reverse supply chains and describes the integration with forward chains. At the PLCm level, interface variables relax constraints in CSC optimisation.

Circular supply chains pose an opportunity. According to Blumberg (1999) the worldwide 'reverse logistics and repair' market in high tech capital goods, consumer electronics, and pallets /packaging alone has grown in terms of yearly value from 17 billion US$ in 1994 to 34 billion US$ in 2000. Given the fact that the many business have not developed advanced concepts, there is still a lot to be gained.

However, things are not as easy as it may seem. Often, returns are not recognised as an opportunity and therefore lack the interest of shareholders and (top) management. Carter and Ellram (1998) develop a model that points to internal (e.g. shareholder commitment) and external drivers (e.g. regulation) needed to respectively ensure the continued success of reverse logistics programs and utilise resources efficiently in carrying out the program. Daugherty et al. (2002) show how management commitment moderates the positive impact of information system support on reverse logistics performance. Diffusion may also be helped by things like ISO 14.000 standards.

In a broader context, industry more and more has to face sustainability related requirements such as safety and occupational health requirements, reduction of energy use, use of clean resources, and so on. Environmental disasters such as the recent floods in Central Europe remind us of the urge to act, and the latest UN conference in Johannesburg confirms that it is not politics but business that must solve the problems. Business developments sketched earlier only make this perspective more logical. Our future work will therefore to continue to focus on value creation from returns and on the supply chain (modelling) consequences. From a supply chain context, other major areas for future research include outsourcing, partnerships and alliances, integration of reverse logistics and installed base management by remote diagnostics and (R)E-commerce applications.

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Appendix: Proposition framework for optimising value creation in circular supply chains

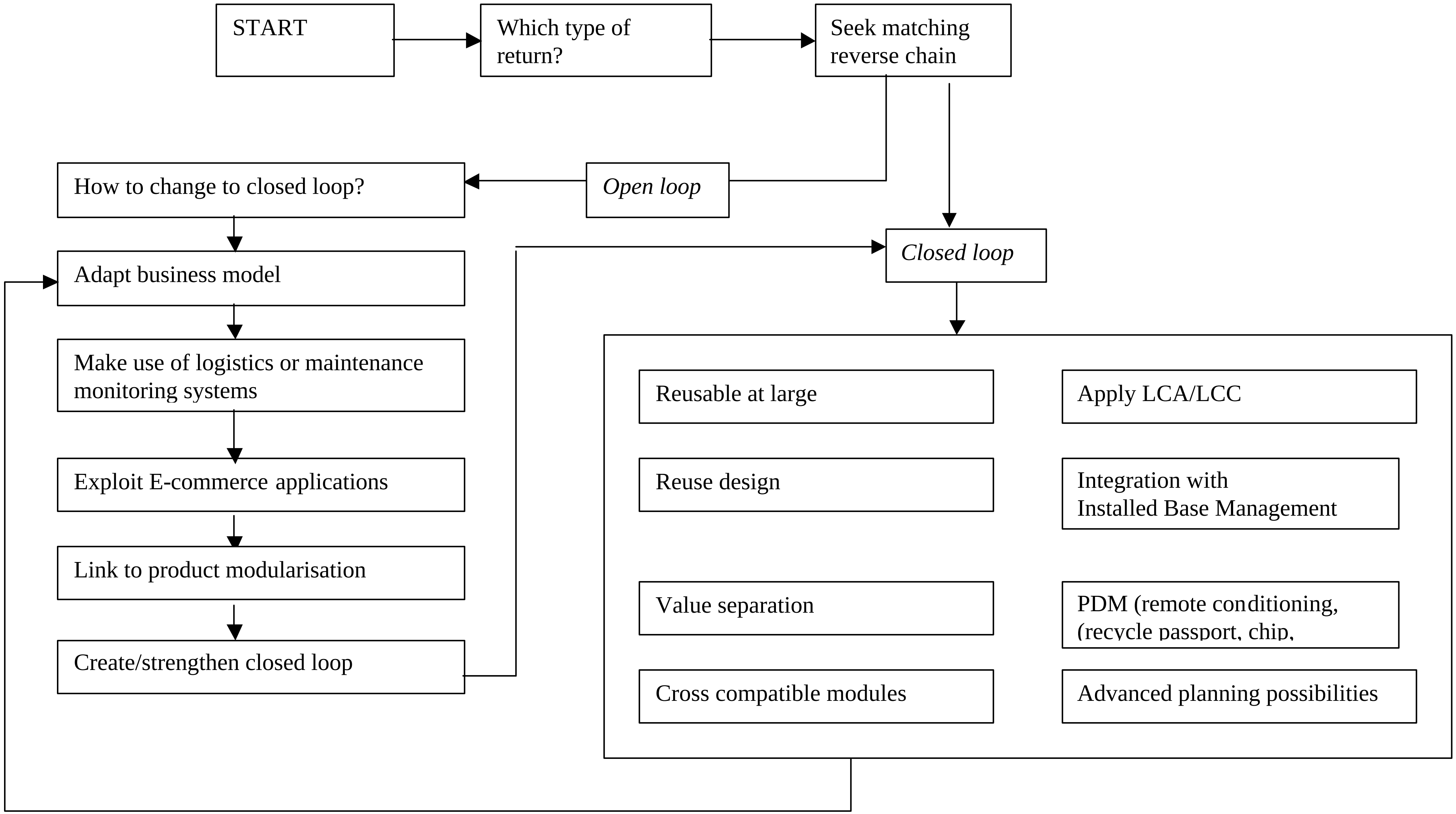
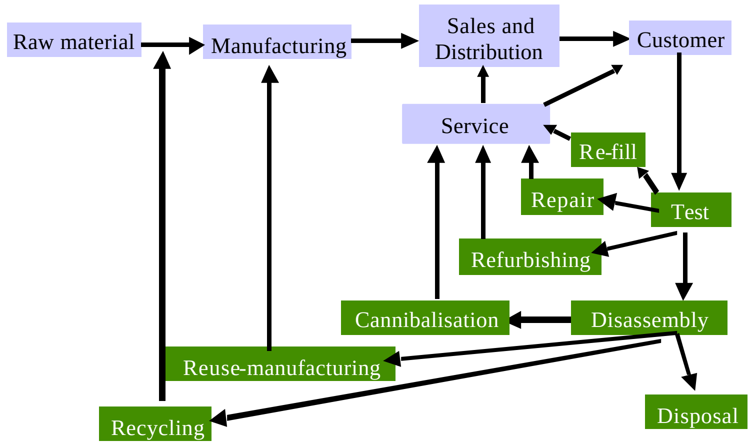


Figure 2: application of the recovery options in multi-loop product life cycle



Supply chain must cover product life cycle

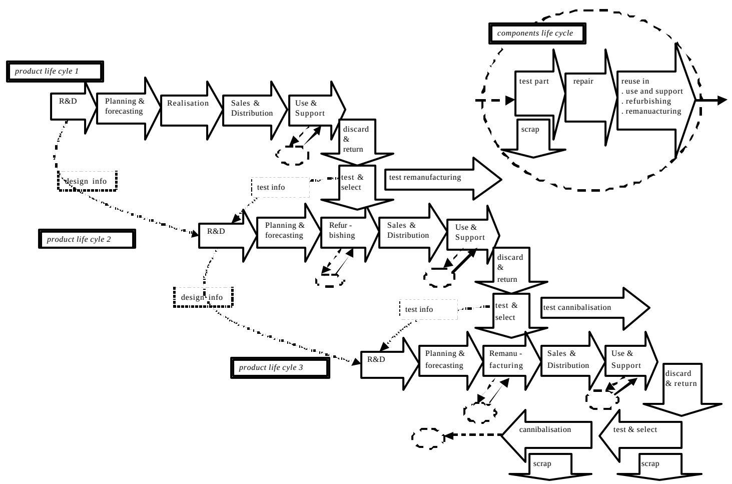
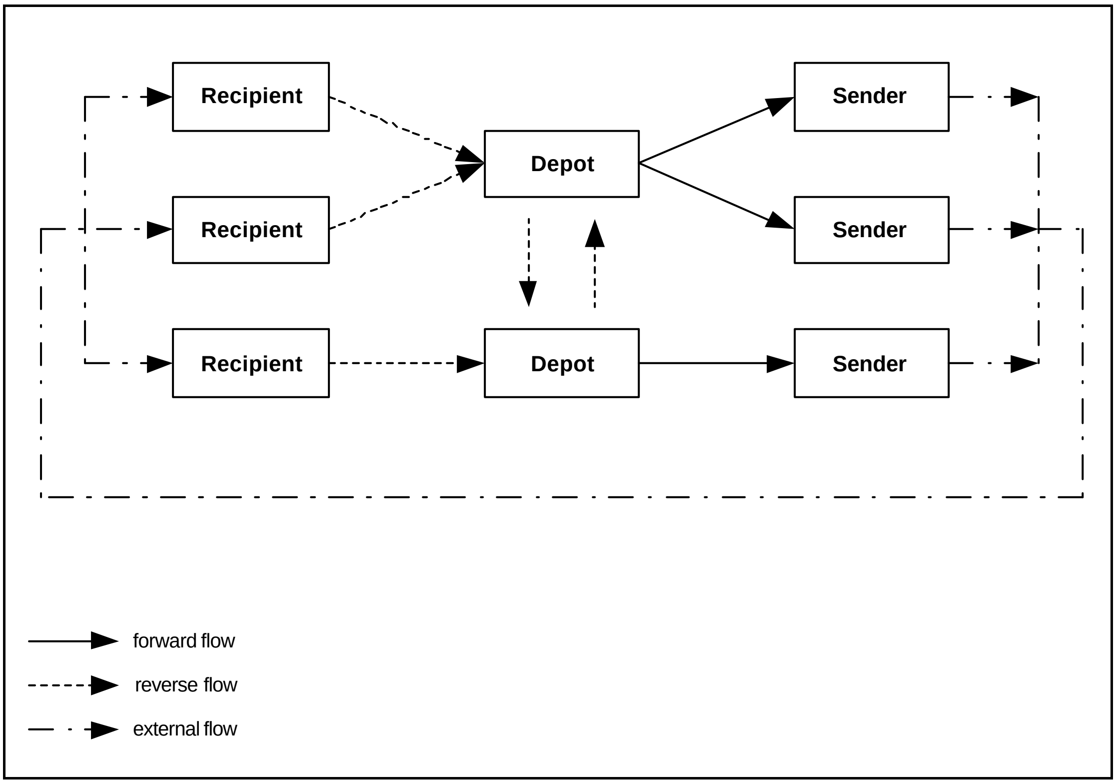
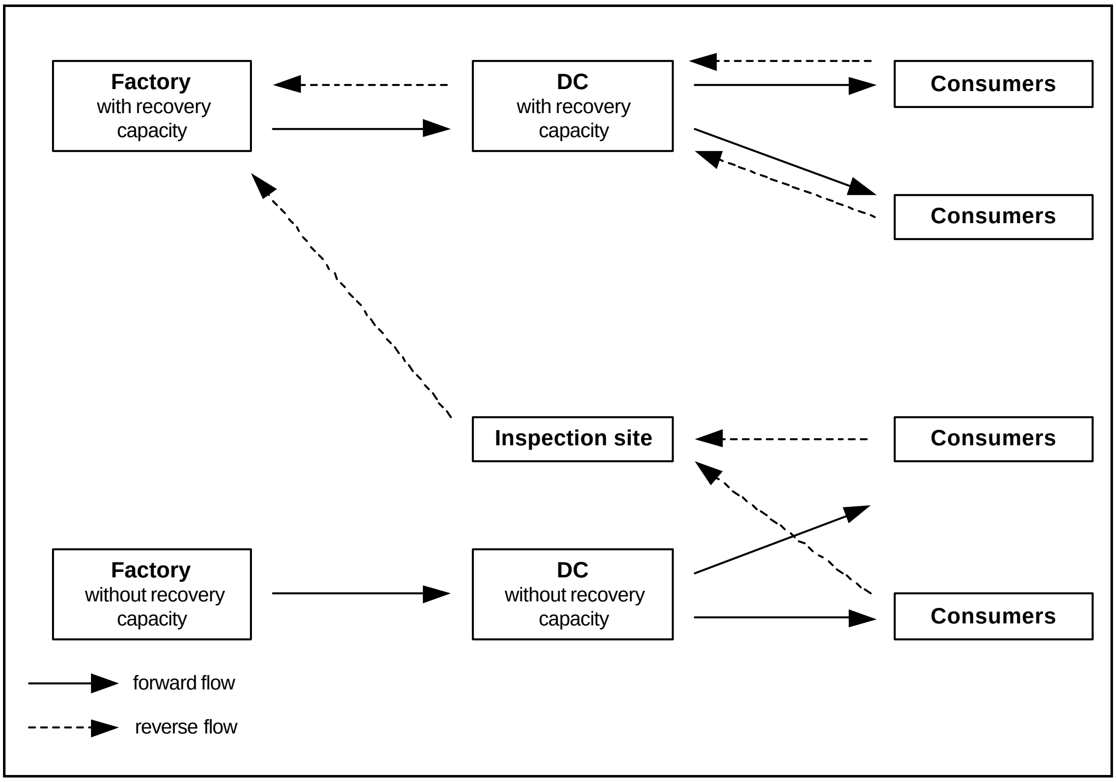


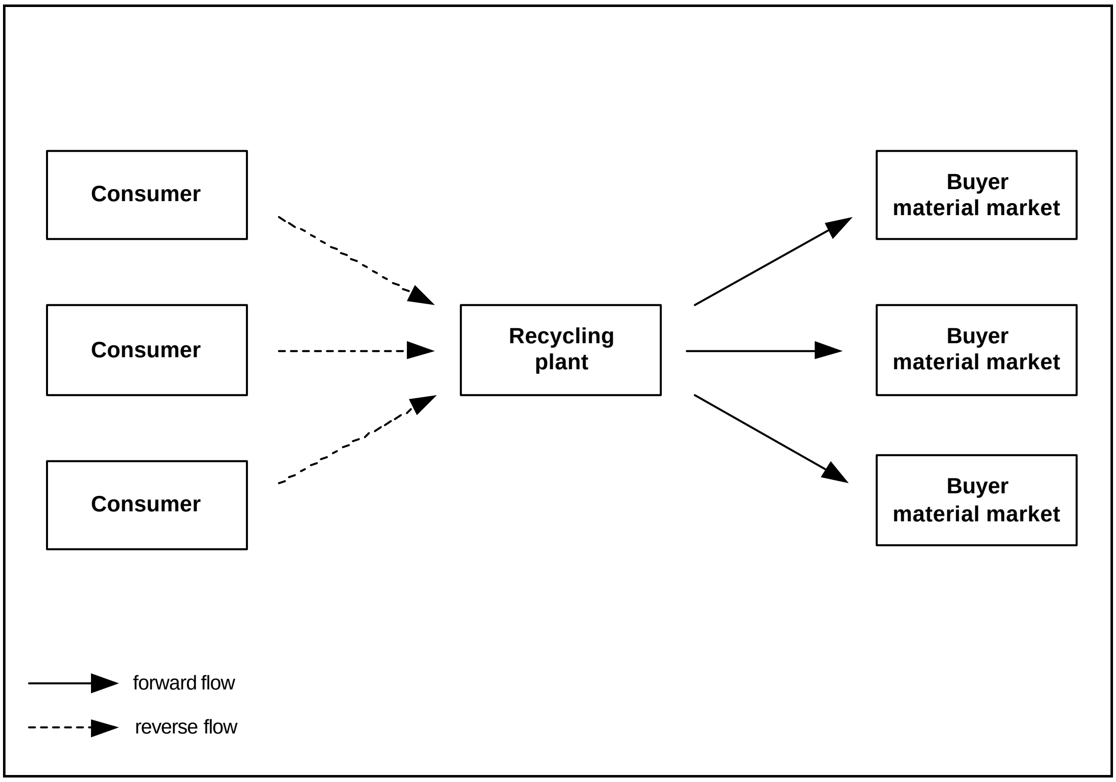
Figure 3: basic shapes of typical circular supply chains



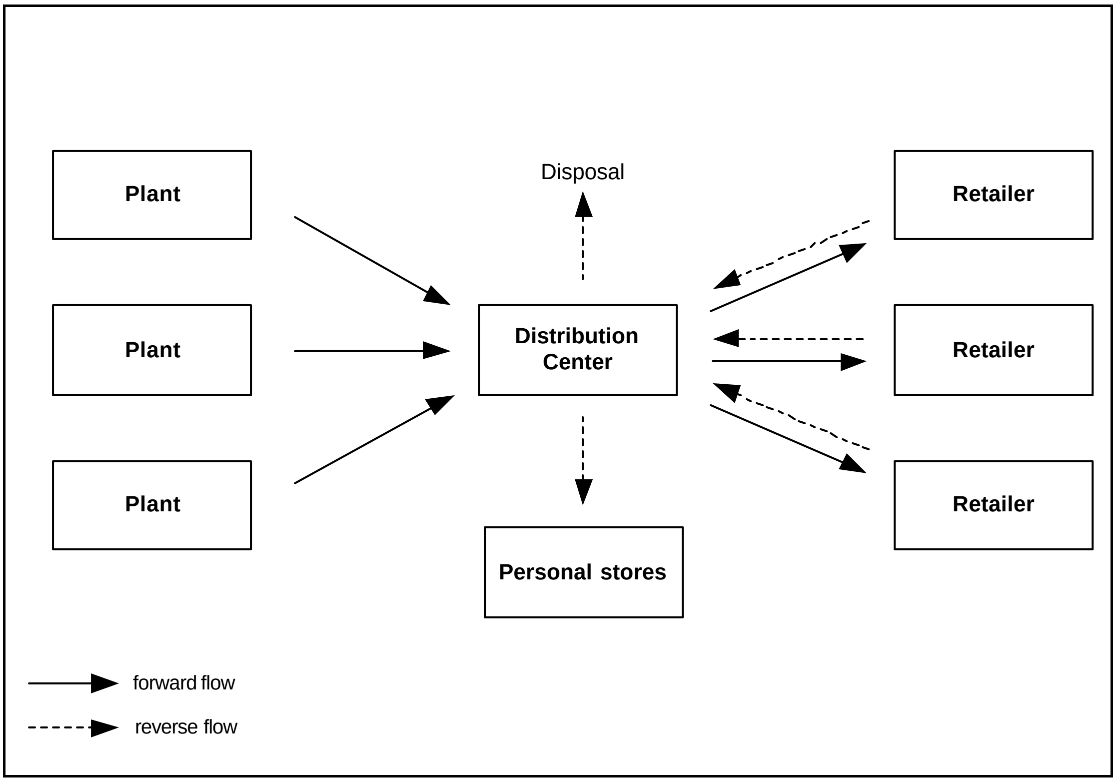
Carroussel



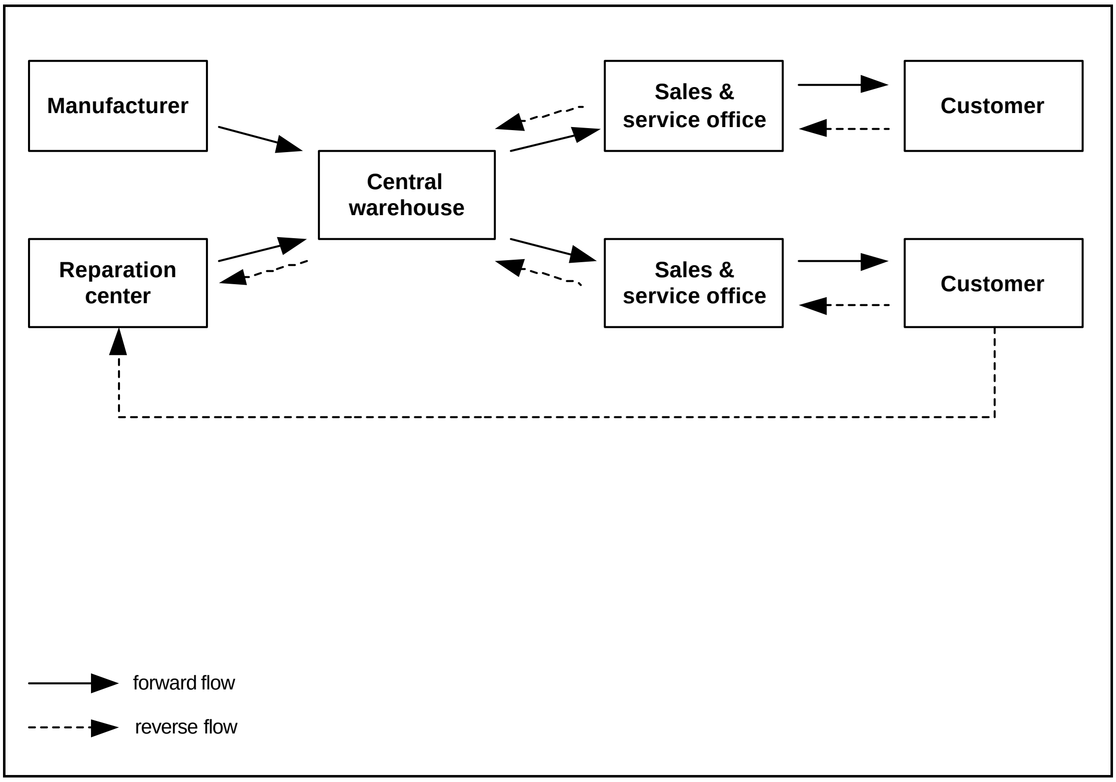
Hybrid manufacturing



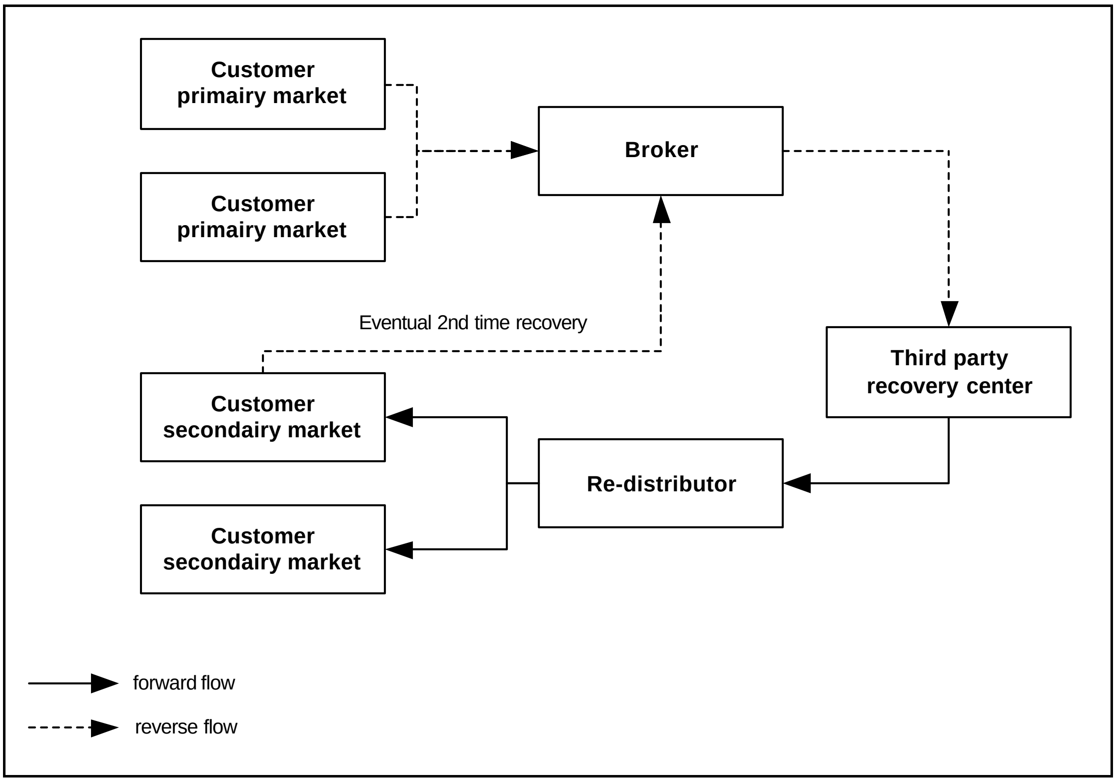
Bulk recycling



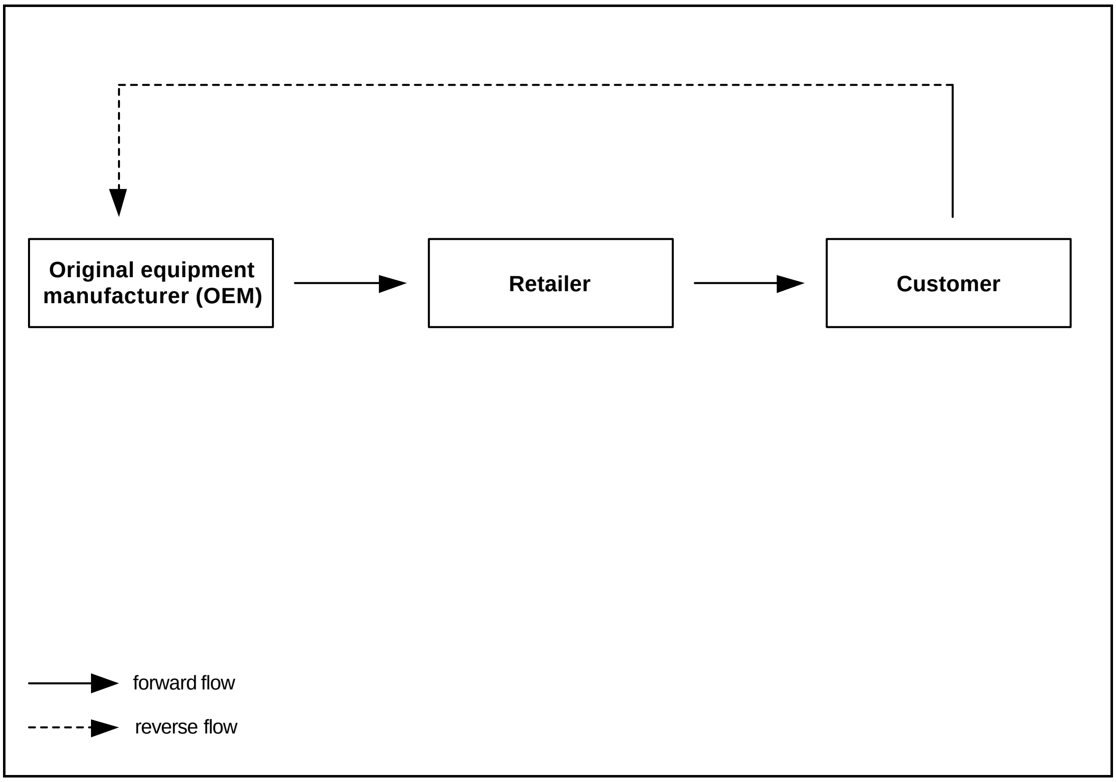
Reverse distribution



Service – repair



Trade - repair



Cyclic replenishment