# DESIGN PRINCIPLES FOR CLOSED LOOP SUPPLY CHAINS: OPTIMIZING ECONOMIC, LOGISTIC AND ENVIRONMENTAL PERFORMANCE

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# Design principles for closed loop supply chains: optimizing economic, logistic and environmental performance

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**Abstract.** In this paper we study design principles for closed loop supply chains. Closed loop supply chains aim at closing material flows thereby limiting emission and residual waste, but also providing customer service at low cost. We study 'traditional' and 'new' design principles known in the literature. It appears that setting up closed loop supply chains requires some additional design principles because of sustainability requirements. At the same time however, we see that traditional principles also apply. Subsequently we look at a business situation at Honeywell. Here, only a subset of the relevant design principles is applied. The apparent low status of reverse logistics may provide an explanation for this. To some extent, the same mistakes are made again as were 20 years ago in, for instance, inbound logistics. Thus, obvious improvements can be made by applying traditional principles. Also new principles, which require a life cycle driven approach, need to be applied. This can be supported by advanced management tools such as LCA and LCC.

**Keywords**: closed loop supply chains, case-study, reverse logistics

## 1. Introduction

Over the past few years increasing volumes of return flows, varying from end-of-life returns to marketing or commercial returns, has reinforced interest in the effective management of such flows. More and more, Original Equipment Manufacturers are held responsible by new environmental legislation for the recovery of their own products. In case the OEM is out of the country, importers are held responsible and new parties, mainly profit-oriented, deal also with the recovery and recycling of used products. This results in closed material flows as shown in Figure 1. A new managerial area called reverse logistics management emerges, which can be described as the process of planning, implementing and controlling the efficient and effective inbound flow and storage of secondary goods and related information opposite to the traditional supply chain, for the purpose of recovering value or proper disposal (Fleischmann, 2000). Typically, this comprehends a set of processes such as collection, inspection/separation, reprocessing (including disassembly), disposal and redistribution (see Fleischmann et. al, 2000).

Closed loop supply chain management goes beyond that. It comprehends all business functions and hence decisions regarding the adaptation of business strategy, marketing, quality management, information systems, logistics and so on in view of closing material flows, thereby limiting emission and residual waste, but also providing customer service at low cost. Both the forward and reverse chain are considered, since there is a strong interaction between the two.

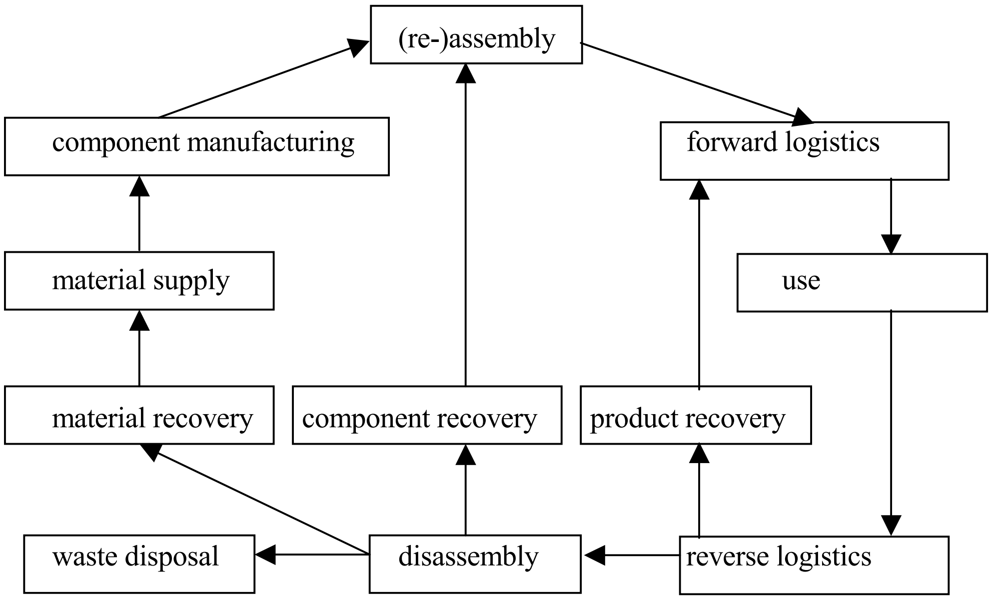

**Figure 1: Forward and reverse supply chain (similar to Ferrer, 1997)**

It is essential to analyze in what respect closed loop supply chains fundamentally differ from forward logistics, and how this affects design principles. Closed loop supply chains are different on the following aspects (Fleischmann et. al, 2000) and (Faucheux and Nicolaï, 1998):

- ❑ In addition to cost and service there are environmental drivers, complicating the objective function.
- ❑ Higher system complexity, in particular in closed loop systems due to increased number of - and interaction between goods flows. Uncertainty on

the supply (collection) side of the system regarding volumes, quality, composition and timing.

- Push-pull nature. There is often a mismatch between supply and demand. “Production” (i.e. supply of used products) is not coupled with “demand” (i.e. producer’s requirements).
- Numerous “suppliers”/ few “customers”. Used products are the raw materials for the reverse chain. Unlike the forward chain, there are a lot more sources of raw materials and they enter the reverse chain at small cost or at no cost at all. However, although obtained for ‘free’, the value of return flows is low and may be limited to a small fraction of the flow.
- Unexplored market opportunities. Environmental requirements can be the basis of the creation of new markets or result in the reorganization of existing ones for by-products of the production process. With such reorganization, materials that would otherwise end as wastes would turn into useful products.

The above distinguishing characteristics might justify the development of special approaches. However, little attention has been paid to the question whether design choices in closed loop supply chains differ from those in traditional ‘forward’ logistics. For example, logistics networks may be more decentralized in closed loop supply chains, but the underlying trade-off between economies of scale and transportation costs might be exactly the same.

The purpose of the paper is to see to what extent design principles, as described in the ‘traditional’ logistics literature, are also applicable to closed loop supply chains and in what respect they need to be extended or adapted. We ask ourselves the following questions:

- What forward and closed loop logistics design principles are known from the literature?
- Are design principles for closed loop supply chains fundamentally different or do different parameter values simply lead to different solutions?
- To what extent are design principles well understood and applied in business practice?

We develop a theoretical framework in Section 2, which is split in a first part concerning design principles from traditional supply chain literature and a second part concerning design principles from closed loop supply chain studies. In Section 3 we discuss the Honeywell case to illustrate application and understanding of the principles in practice. Clearly, one case is insufficient to get a full picture of what’s going on in business practice, however valuable lessons can be learned. In Section 4 we discuss results and draw conclusions.

# 2.Theoretical framework

## 2.1 Design principles in traditional logistics

Several principles, which apply to supply chain (or parts of it) design, are referred to in bibliographies (e.g. Ralph Sims, 1991). A quite comprehensive list of such principles, which appears in (Gattorna, 1997) is described below. Where appropriate, we added the interpretation of these principles for closed loop supply chains.

1. Link logistics to corporate strategy

All aspects of logistics operations must be directly linked to the corporate strategic plan. It appears that many companies do not consider closed loop supply chains as a strategic issue (Caldwell, 1999). However, companies with successful closed loop supply chains, such as Xerox, BMW, 3M etc., do consider asset recovery as essential part of their business.

2. Organize comprehensively

All corporate logistics functions should be unified under a combination of centralized and decentralized management. Grouping all logistics-related functions under a single umbrella facilitates effective decisions. In several studies the authors found that the responsibility for the returns handling was often not clearly assigned, neither in the supply chain nor at a company level.

3. Use the power of information

Successful logistics implementation takes full advantage of information and information-processing technology, not only for data interchange, but also for decision support. Good return management requires up-to-date information on the installed base, making use of product data management systems, remote sensing and tracking and tracing systems. Also, information can be retrieved from returns, for example by analyzing wear out of returned cores.

4. Emphasize human resources

Logistics excellence flourishes in an environment that recognizes people as the department's most important resource. Recruiting, education, training and job enrichment are standard practice. Experienced, well-trained managers are critical to the success of business strategies and plans. In returns management, elderly employees, those who assembled the products 5-20 years ago, are often employed in the Asset Recovery department, since they are the only ones with the knowledge necessary to recover the returns.

5. Form strategic alliances

Forming close partnerships with other participants in the product chain or channel can boost logistics operation. Pre- or non competitive R&D is often done in cooperation. For example, Sony, Motorola, Nokia, IKP, Indumetal and Gaiker jointly develop new construction techniques enabling a returned product, once exposed to the correct trigger temperature, to self-disassemble. But also collection and recovery may be done by joint systems.

6. Focus on financial performance

The logistics function should use return on assets, economic value added, cost and operating standards, or similar indicators as measures of performance. Functions as transportation, warehousing and customer service are best managed as cost or profit centers. So far, reverse logistics is seen as a cost issue by most companies, however potential revenues from reuse and the avoidance of disposal costs is often neglected.

7. Target optimum service levels

Companies need to calculate their "optimum" service levels and pinpoint the costs associated with sustaining those levels. Clearly, only a few companies see reverse logistics as a service tool. For product lines phased out, return flows may serve as a cheap source of spare parts.

8. Manage the details

Attention to details can mean real savings. Effective detail management produces consistency of purpose, objectives, image and information to customers. Obviously, this principle is equally applied to both forward and reverse supply chain design and operations. For example, when tracing cause of returns (failure, bad manual, overadvertising etc.), it is necessary not to have general figures but to analyze carefully per retailer, distribution channel, type of product and so on.

9. Leverage logistics volumes

Successful logistics operations consolidate shipment volumes, inventories and the like to gain operating and financial leverage, whether the logistics function is performed in-house or by an outside contractor. Leveraging can be increased by good collection systems and joint ventures. A problem with return flows is that only a small part is valuable and therefore remanufactured/reused whilst the majority is low value and will be scrapped. Hence, reverse substreams follow different recovery routes which complicates consolidation.

10. Measure and react to performance

Companies must measure their logistics performance and react to the results in an on-going dynamic fashion. Reverse logistics processes should be benchmarked as any other business process.

By definition, closed loop supply chains aim at closing material flows, thereby limiting emission and residual waste, but also providing customer service at low cost. Thus, closed loop supply chains do what traditional supply chains do and in addition contribute to sustainability. Therefore traditional design principles also apply to closed loop supply chains, although in some cases with slight adaptation or different interpretation. In addition, we investigate design principles specifically for closed loop supply chains in 2.2.

## 2.2 Design principles for closed loop supply chains

From a closed loop supply chains point of view, the above list of design principles may be extended to include other important rules. Again we remark that both forward and reverse chain are relevant here. From literature study, we are able to propose the following:

11. Impose sustainability standards on suppliers. Selecting sustainable suppliers requires additional selection criteria. One of the issues to be solved is the supplier paradox: the one supplying reusable parts may loose most business. This needs to be compensated, for example by outsourcing repair to the original supplier, who as a bonus also has most knowledge and dedicated equipment. Also, suppliers may co-design the product to enable modularization and design for recycling. See also (Corbett and Van Wassenhove, 1993) and (Tsoulfas and Pappis, 2001).

12. Make use of accounting systems that account for the full life-cycle costing of a product or service, and the environmental impacts it creates. Based on this, develop and design recoverable products, which should be technically durable, repeatedly usable, harmlessly recoverable after use and environmentally compatible in disposal (Gotzel, et. al, 1999). Extending service and function, especially at the usage phase, improves eco-efficiency and reusability (Tsoulfas and Pappis, 2001). Modularity and standardization also improves opportunities for repair and (cross-supply chain) reuse of components and materials.

13. Make use of management tools, such as ISO 9000-14000, life cycle analysis, environmental accounting methods, that may help business to identify and select opportunities for improvement. For example, using less energy is obviously good for the environment. It is also self-evidently good for business because it cuts companies' costs, and eventually avoids potential environmental liabilities. It is, therefore, a prerequisite to the long-term sustainability of business. To replace non-renewable and polluting technologies, it is crucial to support the use of solar, wind, water and geothermal energy (among others), as well as reduction in energy consumption (Tsoulfas and Pappis, 2001).

14. Create new markets. The environment can be at the basis of the creation of new markets or of the reorganization of existing ones for certain (material) flows resulting from the production process. With such a technical reorganization, materials that would formerly have ended as wastes are turned into useful by-products (Faucheux and Nicolai, 1998). Facilities should be located close to possible end-users. Such a policy would ease the direct delivery of used products from end-users (Angell and Klassen, 1999). Furthermore, companies can also offer waste disposal services (Corbett and van Wassenhove, 1993).

15. Manage additional uncertainty. In recovery situations only a part of the flow is valuable, but it is hard to say beforehand which part. This means that sorting and initial testing should be decentralized to separate junk from valuable returns. The same goes for sorting and volume reduction in e.g. plastics recycling. Intrinsic to the push-pull nature of reverse channels, there will often be a mismatch between supply and demand for recyclable products and choice of the right recovery channels, even in situations with perfect information. E-market places provide a good support tool. Companies that manipulate materials and energy should be organized in such a way that they can respond rapidly to changes in management and processes (Tsoulfas and Pappis, 2001). Changing demands for goods and services will also push design changes. The study of alternative plans is necessary in order to achieve eco-optimization. "Do the same but do it better or try to do

something different."(Klassen and Angell, 1998). Pro-activeness, especially to intended legislation, has proven to be effective in many situations.

16. Match network design with recovery option. Regarding cost and service driven network design, (Fleischmann et. al, 2000) and (Bloemhof-Ruwaard et. al, 1999) give an overview of case studies. They conclude that compared to traditional forward logistics, closed loop supply chains have some distinguishing common characteristics, in particular in terms of processes to be carried out. Typical characteristics of product recovery networks include a convergent part concerned with collection and transportation from a disposer market to recovery facilities, a divergent part for distribution to a re-use market, and an intermediate part related with the recovery processing steps required. Moreover, they derive typical types of networks per recovery option, where they distinguish networks for material recycling, remanufacturing, reusable components, reusable packaging, warranty and commercial returns. These network types generally differ in terms of network topology, the role of and cooperation between actors and the collection and routing system used.

17. Enhance design for recycling. Regarding the environmentally driven network design, in (Tsoulfas et al., 2000), a sector analysis of batteries from the point of view of closed loop supply chains is presented, where several network design criteria are discussed. Environmental aspects may influence network topology, the role and cooperation between actors and the collection and routing system used, and they also raise the issue of product design as a critical element. Decisions to be taken concern modularity, kind of materials, involvement of suppliers (co-design), disassemblability, life cycle considerations (will it last for a long period or a short one?), type of equipment used and standardization of modules/components in the product. Parameters affecting the decision include pollution generated, energy use, residual waste, life cycle cost, production technology, secondary materials, by-products, recyclability, product complexity, product function, and so on.

18. Enhance quality and rate of return. In (Krikke et. al, 2000) a multicriteria model is presented that optimizes the supply chain of refrigerators on both economic and environmental (LCA based) criteria. The model is run for different scenarios using different parameter settings such as centralized versus decentralized operations, alternative product designs, varying recovery feasibility and return quantity, and potential EU legislation. The most important conclusion of the project is that, next to efficient logistics combined with optimal product design, system optimality depends on return quality and rate of return. In fact, in this case study these effects outperform the impact of product design and logistics network structure.

## 3. Remanufacturing of Printed Wiring Assemblies at Honeywell

### 3.1 Case description

Honeywell Industrial Automation and Control (IAC) is a global player in industrial automation. It produces, supplies and maintains Distributed Control Systems, i.e., both hardware and software to measure, monitor and control production processes of its customers. Distributed Control Systems are networks of intelligent (automated) stations, which control an industrial (chemical) plant or process, where the network distributes logic control, data access and process management. Because of the high capital value of the plants involved and their dependence on control systems, the control systems are often redundant, and need fast service in case of failure. In this case, we study the repair of Printed Wiring Assemblies (PWAs). These PWAs are a critical and valuable component in the TDC-3000 system. They are serviced by well trained service engineers of the national affiliates and regularly replaced due to failure or potential failure. Service contracts oblige Honeywell to respond to a customer call within 24 or 48 hours.

The service process goes as follows. After a call, a service engineer is dispatched to the customer location. The engineer replaces the bad or suspicious PWAs and brings it back in his car to the affiliate depot. Here, the PWA is visually inspected. Some parts are rejected and scrapped, others are tested. Good parts are restocked, either at the depot or the engineer's car. Malfunctioning parts are returned for repair after authorization of the central logistics department ISLC. ISLC controls all logistics and tactical support for European customers. Local repair by affiliates also takes place, but is not officially approved. PWAs are returned by truck to the central warehouse for Europe in Amsterdam, operated by Van Ommeren Intexo (VOI) and controlled by ISLC. VOI is a logistics service provider that operates the warehouse and transportation for Honeywell. Returned PWAs are consolidated at this central warehouse and from there transported in large batches to the Honeywell production and repair sites in Phoenix (USA) and Johannesburg (SA) by plane (Burlington Air). Here returned PWAs are inspected and, if feasible, repaired or upgraded. Johannesburg is given priority, because it is more dedicated to repair. However, also here regular production takes place. Johannesburg sends repaired PWAs to the central European warehouse and Phoenix restocks them in their own facility for possible supply to Europe or other warehouses worldwide. As soon as a PWA has been replaced and returned, the inventories are replenished, i.e., the affiliate replenishes the engineer's car, the central warehouse replenishes the affiliate depot and the production factories replenish the central warehouse. Return of repaired PWAs from Johannesburg to the European warehouse runs independently from the replenishment procedure. Also in replenishment, inter-continental transportation is covered by plane, intra continental transport by truck.

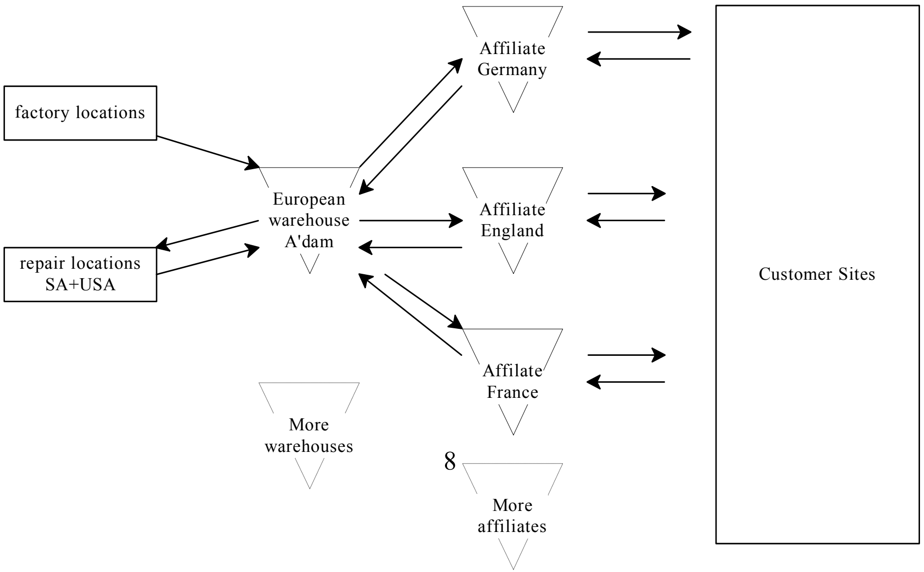

**Figure 2: Honeywell European supply chain for service of TDC 3000-PWAs**

Figure 2 represents the existing closed loop supply chain for service of PWAs for TDC-3000 system in Europe, including return flows for repair. Replenishment rush orders can skip one or more echelons, depending on the cause and location of demand: PWAs can be delivered straight from the factories to the affiliate, from the central European warehouse to the affiliate or from the central warehouse to the customer site. This is done by DHL. Inventories are kept at the production and repair sites, the central warehouse, affiliate locations and in the service engineer's car. In terms of volumes, about 500 are returned each year, of which the majority is remanufactured (note that defects are generally not returned). About 3000 pieces are in stock. Total reverse chain cost are about 360 EURO per item, whereas the reuse value is estimated 700 EURO. The lead-time from the moment of return at the customer site, through repair and back to serviceable stock is approximately 34 weeks, which is a major concern for the management because of the risk of obsolescence. In comparison, the lead-time from production to stock for new spare parts is only 3-4 weeks. For an extensive description of the case, we refer to (Breunesse, 1997). The following shortcomings have been identified:

(i) Return procedure. Non-reusable and reusable PWAs are not separated correctly at the source, because there is no clear procedure and responsibility for return shipping is not assigned. There is a lack of awareness of service engineers that broken PWAs should be returned in a correct manner (e.g. packaged correctly). As a result too many PWAs which are not reusable (due to lack of demand or technical failure) are returned, while reusable PWAs are sometimes not returned.

(ii) Lead-time. Return shipments are done via the forward logistic systems leading to long and also stochastic lead times of returns. In reverse distribution, consolidation times for small return volumes are long and the reusable PWAs that are returned stay too long in the pipeline, due to capacity problems at the production/repair sites. Long lead times are costly due to high capital value of PWAs and danger for obsolescence.

(iii) Availability planning. Also as a result of the long and stochastic lead-time, returned PWAs are not taken into account in the availability planning of ISLC for the VOI warehouse. This is no problem for Phoenix repairables, since they are restocked in Phoenix. However, the Johannesburg repairables are restocked at the VOI warehouse in Amsterdam. They cannot be taken into account in the availability planning, because a lack of logistic control makes lead times long and stochastic, hence Johannesburg is not sufficiently reliable as an internal supplier of PWAs. This is complicated by the fact that valuable information is lost in the long reverse chain, because information does not stay with the product nor is an information system in place to deal with this.

The supply chain improvements suggested in this study were based on the following considerations:
- lead time reduction
- controlling out-of-pocket costs
- no defect PWAs should be returned
- all good PWAs should indeed be returned quickly
- information should be kept with the PWA.

The possibilities for re-design are limited, because existing repair centers (in Phoenix and Johannesburg) cannot be closed down nor can new ones be opened. This is due to the fact that in the near future Honeywell will outsource repair activities. Also, Johannesburg is a priori chosen as the repair facility for Europe, in order to equalize capacity loads company-wide. In other words, only the collection system, goods flows and make-or-buy decisions may be affected. Improvements must be found in simplifying the reverse logistic system. The following solution is suggested: (i) an improved return shipping procedure for service engineers and clients makes sure the right PWAs are returned, (ii) direct shipping by DHL from affiliates to the repair center in Johannesburg reduces lead time and makes it easier to keep information with the PWA. The forward system and the shipping from Johannesburg back to stock in central European warehouse remain the same. This reverse supply chain has a better performance, while unit out-of-pocket cost increases from 360 EURO to 373 EURO per PWA. However, total shipping costs may be reduced because useless returns are avoided by the improved shipping procedure.

## 3.2 Analysis

In the old situation the supply chain is not geared for return flows. This can be explained by two design principles used at the time:
- ☐ Use the forward supply chain as much as possible
- ☐ Minimize out-of-pocket costs per stage in the reverse chain.

We see that lousy performance necessitates the re-design of the supply chain for repair of PWAs. To this end a subset of design principles presented in Section 2 is applied. Table 1 gives an overview of the design principles and their application in the re-design. They are explained below.

Table 1: Overview of design principles application at Honeywell

| **principle** | **description** | **yes, no, somewhat** |
|---|---|---|
| 1 | link to business strategy | somewhat |
| 2 | organize comprehensively | somewhat |
| 3 | power of information | yes |
| 4 | exploit human resources | no |
| 5 | form strategic alliances | no |
| 6 | focus on financial performance | somewhat |
| 7 | target service levels | yes |
| 8 | manage details | no |
| 9 | leverage volumes | yes |
| 10 | performance mgt. | somewhat |
| 11 | use sustainable suppliers | no |
| 12 | use life cycle methodologies | no |
| 13 | use new management tools | no |
| 14 | create new markets | no |
| 15 | manage uncertainty | somewhat |
| 16 | enhance design for recycling | no |
| 17 | match network and recovery option | yes |
| 18 | enhance rate and quality of return | yes |

Honeywell should consider closed loop supply chains as an essential part of their service functions because returns are often the only source for spare parts, especially for phased out products. Using a carrier for speeding up returns reduces lead-time and variance and thus risk of obsolescence and uncertainty. By outsourcing, the network structure is automatically changed. It also avoids organizational and responsibility problems and leverages volumes. However, this is also quite costly, in particular with long distances from Europe to South Africa. A centralized network in Europe would be more feasible, however the phasing out of proprietary hardware of Honeywell and thus the phasing out of own repair operations makes this infeasible. Here we see that business strategy, i.e., the decision to use IBM hardware and to phase out proprietary hardware, has an impact on reverse logistics decisions. Decentralized testing and a simplified returns procedure aim at improvement of rate and quality of return. Keeping the information with the PWAs clearly enhances the power of information. The study described by (Breunesse, 1997) is an extensive performance measurement, however follow up is unclear. The definition of cost is widened, now including obsolescence cost.

Taking a closer look, we see that Honeywell has focused on logistics, operations and information aspects in order to optimize costs and availability. But did Honeywell do the right thing from an environmental point of view? The use of airplanes over long distance is an energy consuming activity. Although reusable PWAs are well taken care of, non reusables are scrapped by local firms, of which no information is available. The company appears to have little ‘product life cycle consciousness’. No sustainable suppliers are used. Moreover, product modularity or more general product design aspects have never been nor will not be an issue. The company is unaware of future environmental legislation on producer responsibility, although at the time this was being prepared by the European Union. The phase out of propriety hardware might help Honeywell in this respect, however this is pure coincidence. In conclusion, sustainability remains a subordinate issue.

## 4 Discussion and Conclusions

Traditional wisdom holds that sustainability is costly and the domain of environmental idealists. Few companies have established closed loop supply chains and the ones that have usually implemented end-of-pipe solutions are enforced by law. (Stock et. al, 1998) present results on the state of the art of Reverse Logistics and conclude –amongst other things- that “the state of development of Reverse Logistics is analogous to that of inbound logistics of 10-20 years ago”. We consider Honeywell a typical example of this. Although one case is insufficient to draw generic conclusions, our hypothesis is that the most eminent mistakes made by business companies are:

- Life cycle approach is missing

Many troubles in recovery phase are caused by bad product design. Reverse chains should be designed in concert with the forward chain. Sometimes this requires a partial redesign of the forward chain as well. Existing supply chains thus strongly affect the design of reverse supply chains but may also be affected themselves. Extend service and enhance function, especially at the usage phase, to improve eco-efficiency and reusability (Tsoulfas and Pappis, 2001). Modularity and standardization also improves opportunities for repair and (cross-supply chain) reuse of components and materials. Suppliers that are sustainable should be selected and involved in product design and component repair.

- Optimization on out-of-pocket costs only

In the reverse chain, next to out-of-pocket costs we must also include obsolescence costs and service related criteria must be included. This is in fact a very old principle. The importance of lead time effects both on costs and service level has been extensively reported in classic logistics literature. However, there is a danger that reverse logistics is going to reinvent the wheel at this point.

- Neglect of sustainability as an optimization issue

It is necessary to develop and design recoverable products, which should be technically durable, repeatedly usable, harmlessly recoverable after use and environmentally compatible in disposal (Gotzel, et. al, 1999). Very important is to add energy use of the entire system as an optimization criterion. Using less energy is obviously good for the environment. It is also self-evidently good for business because it cuts companies' costs, and eventually avoids potential environmental liabilities. It is, therefore, a prerequisite to the long-term sustainability of business. To replace or reduce the use of non-renewable and polluting technologies, it is crucial to support the use of solar, wind, water and geothermal energy (among others), as well as to reduce energy consumption. A number of management tools, such as environmental assessment, life cycle analysis, environmental accounting methods, but also 'simple' logistics principles can help business identify and select opportunities for improvement.

In conclusion, closed loop supply chains are fundamentally different from traditional 'open' supply chains, particularly in view of sustainability. As a result, traditional design principles need to be extended. However, also traditional principles apply to closed loop supply chains. We suspect that both are often not well understood by business practice. Thus, obvious improvements can be made by applying traditional principles. This is the easy part. New principles are necessary to reduce emission and waste, and require life cycle driven approaches supported by advanced management tools such as LCA and LCC. A new attitude is needed, both with supply chain actors and consumers.

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