USAGE OF STRATEGIES AND ICT TOOLS IN AUTOMOTIVE INDUSTRIES DURING RECOVERY TASKS

- A literature review

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Abstract: Products end of life is increasingly important and there are stronger demands on manufacturers to provide viable options at the end of the product life cycle. In the automotive industry stronger legislations combined with other factors contributes to this importance. Thus, the decisions for recovery are also gaining significance. Strategies and ICT tools could assist decision making in the recovery process. This paper summarises a literature review regarding the existence and usage of strategies and ICT tools, mainly in the automotive industry.

Keywords: Virtual tools, recovery, decision-making assistant, information flow.

1. INTRODUCTION

During the last century there was an increased focus on environmental issues, global conferences have been held and a lot of research efforts have been made. For example the "Bruntland" commission was arranged where the definition of sustainable development as "a development that meets the needs of present without compromising the ability of future generations to meet their own needs" was founded (Brundtland, 1987).

In the last years it has also become evident that what happens with the product after the use face is important for the environmental impact from the product. The end of life (EOL) for the products caught attention and it became of interest for legislators. In general the manufacturers have increased responsibility to take care of their products at the end of the product life cycle than a century earlier, legislations have been one reason for this. For the automotive industry the legal requirements on end of life are increased in Euro 6 (EC 2007) which increase the incentive for recovery operations.

Apart from laws, moral and ethical responsibilities as well as profitability are the main aspects used to convince car manufacturers to support the creation and management of recovery systems. However, these reasons are not sufficient to explain their involvement. According to (Seitz, 2007) a few other reasons could be: the necessity to be independent in terms of price and availability of spare parts; the will of protecting their brand image against independent remanufacturers; or the need to ensure to customers a competent service and repair network.

Armed with these motivations, several researchers have published papers that study how the knowledge collected during the early or late stages of production should be spread all along the product life cycle. The purpose is to make information reachable as soon as the decision-makers, engineers, designers or workers need it. (Gerrard & Kandlikar, 2007) identify three areas to improve:

(1) Product design. Owing to the redundancies of failures and the cost of wastes, products should ease each of the several recovery operations they pass through. Unfortunately, some steps of the various processes such as disassembly or cleaning cannot be carried out efficiently if the product is not designed for the outset with this in mind. Researchers have so developed a lot of tools in order to support designers in

their mission. Each method presented aims at increasing reliability, maintainability and safety to ensure the product's ability to be quickly restored.

(2) Information flows. As (Parlikad & McFarlane, 2007) proved in their paper, decisions-makers need to have as much relevant information as possible to make the most suitable choice regarding the recovery option. To do so, a lot of researchers have participated to increase the knowledge in this area. While some of them focused on gathering the relevant information, others deal with the IT technologies that could be used to collect data.

(3) EOL decision. Finally, once the product is designed and the necessary information is established decision-makers step in. In order to help them choose the most suitable process between all the different recovery options, researchers have introduced diverse methods, tools and frameworks.

Operations undertaken by manufacturers should for several reasons be efficient, *e.g.* cost and profit requirements. Hence, it is also important that the decisions and operations for recovery are correct and efficient. At present, the majority of decisions taken for or during the late stages of a product's life cycle are performed without a scientific or systematic analysis. Recovery options must be an exact science to be economically viable and to encourage manufacturers.

1.1. Aim

The aim of the research was to make a literature study regarding:

- the industrial needs for the end-of-life strategies
- existing technologies used today in the early and late product life cycle stages to facilitate recovery decisions
- the information collection process

1.2. Delimitations

It is important to note the delimitations of this study. This study is limited to 183 papers that were found during the literature search, of which a few are summarised in this paper. Although this study is specifically targeted at the automotive sector, a number of papers focusing on other product types have been studied to better understand the research in this sector.

2. RECOVERY OPTIONS

The usual product flow begins with the design, goes on with the production and consumers' use, and "ends" with a first disposal. Indeed, since technology improvements are really fast, a lot of customers abandon their product to buy a new one. However, the neglected product still possesses a value which is wasted. To avoid that, and to contribute to sustainable development, manufacturers should focus on how to re-use these commodities. A large part of the literature deals with the eight different End-of-Life (EOL) options that are illustrated in Figure 1. These will also be used in this article.

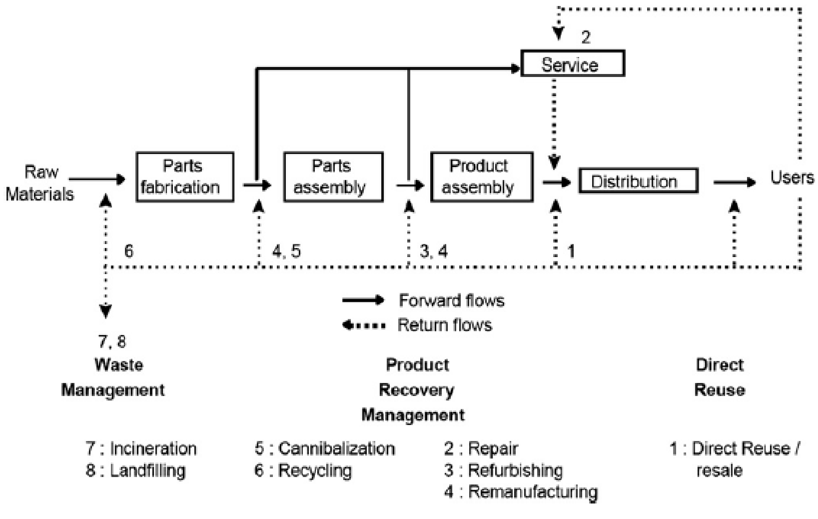


Fig. 1. The different EOL solutions proposed by (Gehin et al., 2008).

A number of authors, (Pintelon et al., 1997) first, laid the emphasis on the unavoidable need for companies to include the second life in the production process, not as a necessary evil, but as a way to increase benefits and competitiveness. They proposed several methodologies or virtual tools to handle it and improve the process.

3. EARLY STAGES OF PRODUCTION

Considering that a lot of recovery operations cannot be run through if they are not facilitated on beforehand, researchers agree on the fact that design must enable and help the product's second life. As it has been said before, several EOL strategies are possible, and designers have to first choose the most suitable one. Scientists studied it and a few papers, presented in 3.1., deal with a helping decision-making tool. Once the best EOL has been selected, a wealth of literature, presented in 3.3., exists to aid designers in design for recovery.

3.1. Decision-making assistant

Before designing a product and its End-of-Life, designers should choose the recovery option they will use. Some tools do exist in the early stages of production to assist them, but none of these tools could foresee the product's quality after use and, consequently, it's impossible at present to provide for the chosen EOL without uncertainties. Nevertheless, thanks to the behaviour of the owner and the state of previous products, it is possible to have a database through which the software could figure out the EOL that will be chosen with the highest probability. It helps designers to concentrate their efforts on a particular type of design. Three major decision-making aid exist today.

REPRO^2 (REmanufacturing PROduct PROfiles). This tool aims at comparing real systems to a database in order to find a match between them. To create this software, (Gehin et al., 2008) have characterized different interesting situations in laying the emphasis on several criteria. They have then compared the situations between them in order to build profiles. They have clustered lifelike situations together and obtained eleven products outlines. In comparing the future product with them, designers could identify the most likely recovery option and get adapted guidelines provided by the literature. With REPRO^2, the authors equip designers with an easy-to-handle tool giving results that could immediately be used. Unfortunately, the software only identifies the closest product behaviour and does not dispense any environmental or economic assessment of the different choices.

ReStar. This is not the case of the methodology suggested by (Zussman, Kriwet & Seliger, 1994) that considers at one and a same time, the products state as well as technical, environmental and commercial aspects to reach the optimal "design for recycling". Even if the assessment is more complete in that case, to determine the most appropriate EOL solution remains difficult due to the level of uncertainty. Indeed, the external environment of the product at its EOL could not be known, and the market situation, product quality, or conditions of use are unsure. To solve it, the authors presented a framework that integrates probabilistic design methods into the concept of utility theory. They first suggest to identify all the possible disassembly solutions through an AND/OR graph. Then, thanks to the utility function they have created, they can assess the ease and usefulness of recovery for each possible disassembly, with regards to all the aspects mentioned above. Finally, these calculations will enable decision-makers to choose, for every node, whether to continue disassembly or to recycle the obtained component. Regarding the final best sequence, the most suitable EOL strategy can be established.

End-of-Life Design Advisor (*ELDA*). (Rose, Ishii & Stevels, 2002) also developed a method that consists of a classification tree based on six product characteristics (wear-out life, technology cycle, level of integration, number of parts, design cycle and reason for redesign). Dependent on which phase of the product life cycle, one of these six criteria is more important and can be assessed to identify the most suitable EOL strategy. The paper thus presents a way to assess these criteria through the classification tree above (see Figure 2). Thanks to it, the decision-makers could plan, with an accuracy of 86%, the least environmentally harmful EOL strategy in regards to the product. This method has been computerized, and ELDA provides design recommendations and guidelines adapted to the identified EOL solution. In addition to it, the ELDA tool and the guidelines are available on the Internet to enable all the actors to collaborate and synchronize theirs efforts about EOL issues.

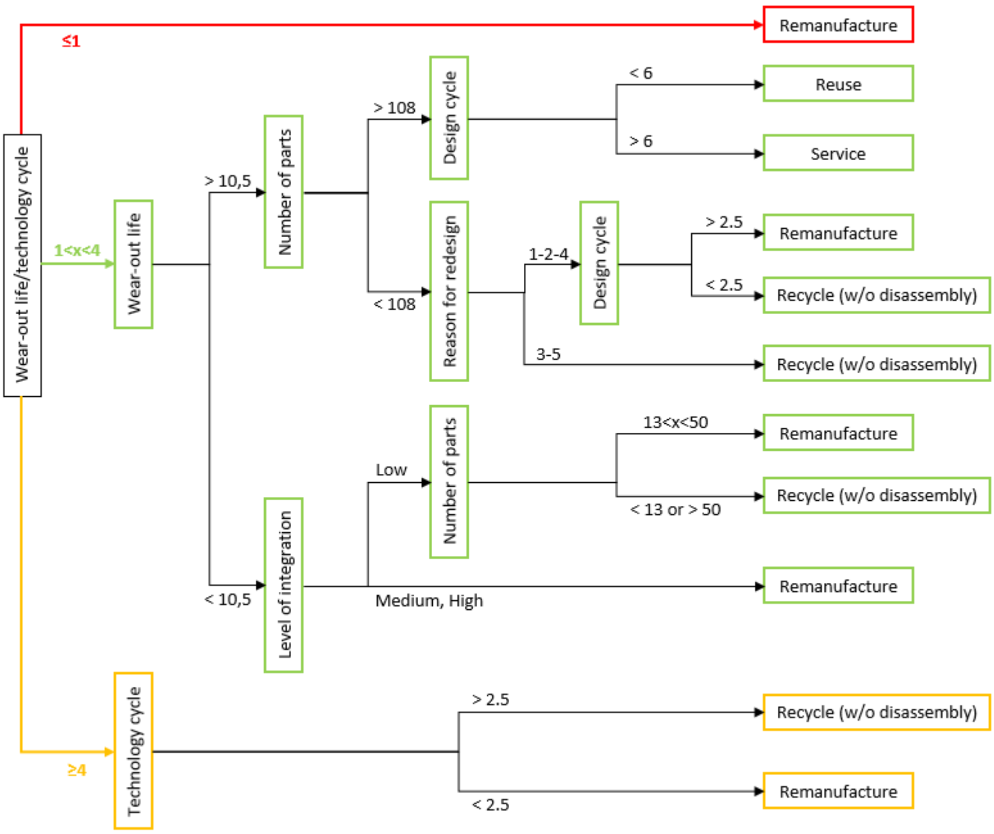


Fig. 2. Classification tree based on six product characteristics, released by (Rose, 2000).

3.2. Methodology

Once the best EOL is identified, designers form Research & Development need some guidelines and assessment methodologies to really design for recovery. (Mildenberger & Khare, 2000) propose a R&D methodology to create, improve, assess and implement new designs or design improvements. The method presented contains seven steps, as show in Figure 3, but we'll only focus on the fourth and fifth part in this section.

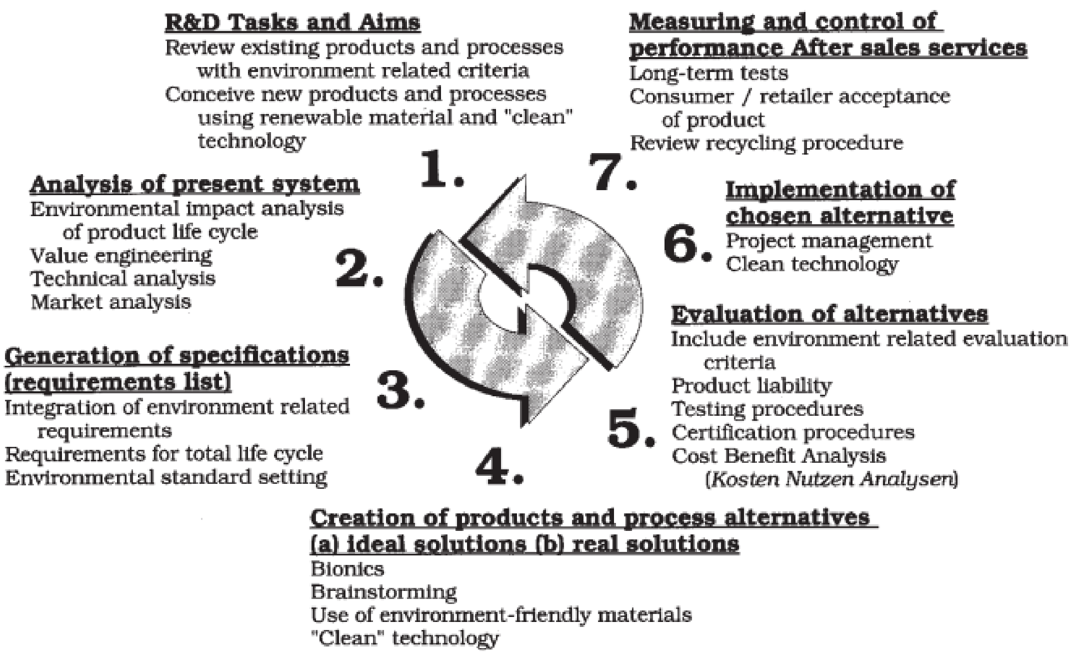


Fig. 3. R&D methodology for environmental-friendly products (Mildenberger & Khare, 2000).

The fourth step deals with the design guidelines aimed at easing a particular recovery option. The most well-known designing help are the Design for X (DfX) guidelines displayed in the next section. Here X could be one of the various EOL options that have been listed in the previous paragraph, or one of the criteria that stem from them (refer to section 3.3.).

The fifth part of (Mildenberger & Khare, 2000)'s methodology provides design assessment to evaluate the alternatives and ensure improvements. (Kobayashi, 2005), for instance, suggests the use of the Product Lifecycle Planning (LCP). It aims at helping the designer to establish an eco-design concept for a product. This method is interesting because the environmental impact is integrated to quality and cost aspects at early design phases, while respecting customers' demands such as cost and performance.

3.3. Design for X and other guidelines

Once the best EOL strategy has been identified and design alternatives suggested, designers need to have criteria to focus on and methods to assess them. Design for X (DfX) is the most common methodology due to its ability to approach the design from a particular perspective. To describe DfX, we will first introduce the criteria, also called maintenance attributes. Numerous and widespread, the maintainability attributes enable emphasis to be put on the important aspects that should be improved to ease the EOL strategies, such as maintainability or disassembly.

The DfX will provide guidelines and support assessment with regards to one of these particular attributes. In that case for instance, designers will have to refer to Design for Maintainability or Design for Disassembly. All these "design for attributes" will contribute to the "design for EOL solution", for example Design for Remanufacturing (DfRem). In this section we will particularly focus on Design for X where X stands for recovery or maintenance and safety.

Criteria. (Wani & Gandhi, 1999) took an interest in durability and figured out that system failure is inevitable, whether it's because product design does not satisfy the customer anymore, or because the product mechanically fails. To improve the ability to be quickly restored or updated, the authors suggest to pay a particular attention to the maintainability attributes. These following features characterize or ease maintenance of a system from a design, personnel and logistic support point of view: accessibility, disassembly/assembly, standardization, simplicity, identification, diagnosability, modularization, tribo-concept, ergonomics, system environment, tools and test equipment, and documentation.

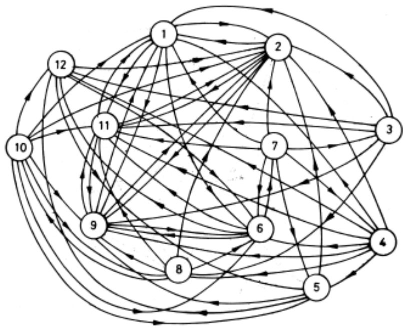
Design for recovery. The recovery options are numerous and enable time and money to be spared in avoiding the manufacture of a completely new product or the disposal of used ones. Despite the quantity of options, lot of researchers rather focused on remanufacturing. This option is the process of returning a used product to like-new condition with a warranty to match. Parts which cannot be brought back to original quality are replaced, meaning the final remanufactured product will be a combination of new and reused parts. Remanufacturers have then to ensure that the remanufactured goods meet or exceed newly manufactured product standards.

(Hatcher, Ijomah & Windmill, 2011), for instance, present a State-of-the-Art on remanufacture. They present an overview of the aids for Design for Remanufacturing (DfRem), as well as a summary of recommended design concepts appropriate to DfRem, and some DfRem research methodologies. They notably show that a lot of helping tools do exist, but that only few of them are actually used.

Among these aids, the RemPro-matrix proposed by (Sundin & Bras, 2005) highlights the sensitive points designers should take particularly care of. Indeed, the RemPro-matrix shows the relationship between the essential product properties to ease remanufacturing, and their intervention in the remanufacturing process. For example they observed that remanufacturing (particularly inspection, cleaning and disassembly) could be facilitated by improving the ease of identification, access, handling and separation; and the wear resistance.

Design for maintainability and safety. As it has been said before, the product state cannot be foreseen in the design stages, and products must be designed in a way that maintainability is facilitated.

In addition to the maintainability attributes list, (Wani & Gandhi, 1999) proposed a procedure aiming at assessing them. To do so, they evaluate how one attribute facilitates others for maintainability, and store these relations on a scale from strongly to absolutely not correlated. These degrees of facilitation could be gathered in a graph as shown in Figure 4 where an arrow links all the attributes that are correlated. However, the graph becomes complex if all attributes and theirs interrelations are considered. To facilitate the visualization process, (Wani & Gandhi, 1999) present a matrix representation. Thanks to this matrix and the procedure described in further details in the paper, the maintainability index could be obtained. It enables the maintainability of each possible system to be identified and compared, thus supporting designers and practicing engineers to compare various alternatives of a system from a maintainability point of view during the early stages of production.



$$\mathbf{M}^m = \begin{bmatrix} V_1 & f_{12} & 0 & 0 & 0 & f_{16} & 0 & 0 & f_{19} & 0 & f_{111} & 0 \\ f_{21} & V_2 & 0 & 0 & 0 & 0 & 0 & 0 & f_{29} & 0 & f_{211} & 0 \\ f_{31} & f_{32} & V_3 & 0 & 0 & 0 & 0 & f_{38} & f_{39} & 0 & f_{311} & f_{312} \\ f_{41} & f_{42} & 0 & V_4 & f_{45} & f_{46} & 0 & f_{48} & f_{49} & 0 & f_{411} & f_{412} \\ 0 & f_{52} & 0 & 0 & V_5 & 0 & 0 & 0 & f_{59} & 0 & 0 & f_{512} \\ 0 & 0 & 0 & 0 & 0 & V_6 & f_{67} & 0 & f_{69} & 0 & f_{611} & f_{612} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & V_7 & 0 & 0 & 0 & f_{711} & 0 \\ 0 & f_{82} & 0 & 0 & 0 & f_{86} & 0 & V_8 & f_{89} & f_{810} & f_{811} & 0 \\ f_{91} & f_{92} & 0 & 0 & 0 & f_{96} & 0 & 0 & V_9 & 0 & f_{911} & 0 \\ f_{101} & f_{102} & 0 & 0 & f_{105} & f_{106} & 0 & f_{108} & f_{109} & V_{10} & f_{1011} & f_{1012} \\ f_{111} & f_{112} & 0 & 0 & 0 & 0 & 0 & 0 & f_{119} & 0 & V_{11} & 0 \\ 0 & f_{122} & 0 & 0 & f_{125} & f_{126} & 0 & 0 & 0 & 0 & 0 & V_{12} \end{bmatrix}$$

Fig. 4 . Degrees of facilitation and associated matrix proposed by (Wani & Gandhi, 1999).

(Coulibaly, Houssin, & Mutel, 2008), as for them, add the parts criticality to the criteria, *i.e.* the ability of the system to operate with a certain failure tolerance depending on the components technical functions, and the parts reliability. They draw a framework for behavioural assessment aimed at evaluating the criticality and reliability of the part components and the difficulty of disassembly. To do so, they build a product semantic matrix that considers the notion of functional link and information about possible relative movements between two components. A value is given to each link type depending on the removing time required. The higher the value is, the more difficult and long disassembly is.

A significant difference with (Coulibaly et al., 2008) is the consideration of safety with regards to the intrinsic, operational and informative perspective. These three perspectives respectively answer the question of how risks could be reduced through product design, work place design (*e.g.* safety barriers) and information documentation (*e.g.* posters). Safety is evaluated with a factor of risk and an index (*i.e.* the hazard) of risk. The first factor enables to define if there's a risk for the human operator or not regarding the hazard of the technical solution, *i.e.* the zone generated by the dangerous phenomenon and the human intervention. The second one takes into account the gravity of the risk (nature and anatomic level), the exposure duration and frequency, probability of it happening and the one of avoiding the accident. This behavioural semantic module is an extension of a CAD 3D tool.

Another interesting paper is the one written by (De Leon, Díaz, Martínez & Márquez, 2012) that assesses maintainability attributes through a graphical representation (example in Figure 5) and five levels of maintenance. Thanks to this distinction, the authors are able to classify the attributes displayed in (Wani & Gandhi, 1999) in regards to their general or specific scope. The general attributes are those affecting any device maintenance level, while the specific attributes are those depending on them. Each attribute is graded from 1 to 4, according to the authors' notation. Maintenance attributes are then gathered to create two different types of maintainability indicators: the general maintainability indicator (GMI), which results from the device general attributes assessment; and five specific maintainability indicators, one for each maintenance level, as a result of assessing the specific attributes of the device.

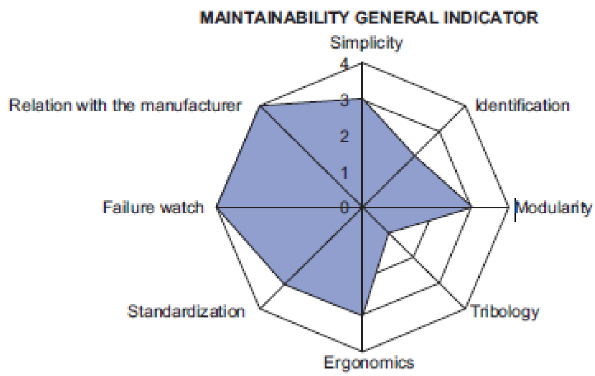


Fig. 5. An example of a graphical representation of general maintainability indicator proposed by (De Leon et al., 2012).

4. LATE STAGES OF PRODUCTION

Design for remanufacturing and EOL strategies are a wide topic for research. However, only one decision-making aid is quoted in the literature: the ReStar tool (Krikke, Van Harten & Schuur, 1998). First, the products are tested and classified in regards to their current state (quality level and the feasibility of every recovery option) and the technical, environmental and commercial criteria. Thanks to input data previously found out and the authors' mathematical model, the optimal strategy is emphasized, and decision-makers are thus enabled to take the right decision. If the disassembly is allowed by the best strategy, it's processed and the mathematical model is used again for evaluating the best recovery option applicable to the now disassembled parts. Depending on the quality level and the recovery feasibility, the entire product as well as module, part or material could be recovered.

Product quality can be easily assessed but feasibility needs evaluation methods. (Krikke et al., 1998) suggest to control it with regards to the revenues of secondary end products while others rather take into account the Remaining Useful Life (RUL) such as (Si, Wang, Hu & Zhou, 2011) or (Mazhar, Kara, & Kaebernick, 2007). An asset RUL depends on the current age of the asset, the operation environment and the observed condition monitoring (CM) or health information. This estimation is expressed as a mathematical function and is calculated as the probability of a certain duration for the remaining useful life in regards to the history of operational profiles and CM information up to time considered.

5. INFORMATION FLOW

The increasing pressure on manufacturing companies to manage their End-of-Life products leads to the criticality of having information available to improve product recovery decisions(Parlikad & McFarlane, 2007). Thus, communication between different actors of the production chain is essential to ensure the application of the most suitable EOL solution and the best management of resources.

Required information. Researchers first figured out when and what kind of information is crucial for an efficient production, in a forward and backward way, as shown in the tables 1, 2 and 3.

Table 1. Main data of information flows for BOL by (Kiritsis, 2009).

	Category	Main data
MOL	Maintenance and failure information for design improvement	Ease of maintenance/service, reliability problems, frequency of maintenance, failure rate, critical component list, root causes, etc.
	Technical customer support information	Customer complaints, customer profiles, response, etc.
	Usage environment information	Usage condition (regarding the external environment) and time, etc.
EOL	EOL product status information	Product/part/component lifetime, recycling/reuse rate of each component or part, etc.
	Dismantling information	Ease to disassemble, reuse or recycling value, disassembly cost, remanufacturing cost, disposal cost, etc.
	Environmental effects information	Material recycle rate, environmental hazard information, etc.

Table 2. Main data of information flows for MOL by (Kiritsis, 2009).

	Category	Main data
BOL	BOM information	Product/part/component ID and design, product structure, etc.
	Information for maintenance/ service	Spare part ID and price list, maintenance/service instructions, etc.
	Production information	Production instructions and data, production plan, inventory status, etc.
EOL	Recycling/reusing part or component information	Information about remanufacturing part or component, etc.

Table 3. Main data of information flow for EOL (Kiritsis, 2009).

	Category	Main data
BOL	Product information	Material and BOM information, costs, disassemble and assembly instructions, etc.
	Production information	Production date, lot ID, etc.
MOL	Maintenance history information	Number of breakdowns, parts/components' IDs in problem, list of replaced parts and date, aging statistics after substitution, maintenance cost, etc.
	Product status information	Degree of quality of each component, performance definition, etc.
	Usage environment information	Usage condition (regarding the external environment) and time, etc.
	Updated BOM	

Information state. Three different types of information nature have been distinguished by (Parlikad & McFarlane, 2007): static (*i.e.* information that remains constant all along the process), dynamic (*i.e.* the contrary) or external (*i.e.* information that depends on factors that are not associated with the product). Depending on this nature, a particular device should be used to enable monitoring the progress of a product state at any stage in its lifecycle. Thanks to Product Embedded Information Device (PEID) developments, decision-makers could now have visibility of not only forward but also backward information flows during the whole product lifecycle.

Embedded technology. Among all the possible approaches, researchers have focused on the embedded technology because it enables data to be both gathered and updated all along the product lifecycle. (Saar & Thomas, 2003) as well as (Parlikad & McFarlane, 2007) suggest to link information technology to materials and products through the use of bar codes and radio-frequency identification (RFID) tags. Both have strong advantages in regards to price, data storage capacity and wear-resistance. (Saar & Thomas, 2003) then propose to use bar codes for products with a short life cycle, and RFID for products with a long life cycle (or if bar codes could be damaged).

Analyses and sharing. Once the information is gathered, they must be released in an understandable way to be useful to the workers that need them. (Klausner & Gimm, 1998) and (Kiritsis, 2009) have looked into the problem, and they propose a similar structure to present the information. According to them, embedded technology should be supported by a Product Knowledge and Management System (PDKM) and a Decision support system (DSS). The PDKM's objective is to manage information and knowledge generated during the product lifecycle. It must be able to acquire, store, share, and secure understandings, insights, and core distinctions. The DSS transform gathered data into necessary information and knowledge for specific applications.

6. DISCUSSION

This section's goal is to list the missing links identified through the state-of-the-art literature study. Communication is a large problem which needs further efforts. A miscommunication between all the actors of the production process, e.g. researchers, designers, EOL decision-makers, could lead to waste of time and money.

Researchers-Companies. The first mismatch noticed has been underlined by (Hatcher et al., 2011). In their paper they show that a lot of tools do exist to help design, but that only a few of them are actually used. There could be several reasons for it:

(1) A lack of information towards companies that do not clearly understand the importance of remanufacturing. Focus should be done WHY remanufacturing and recovery in general could bring benefits.
(2) A customers' misunderstanding or bad opinion about remanufacturing. Advertisement about all the advantages a customer could have might be a solution.
(3) A mistake in regards to the designers' needs. Perhaps tools are far from user-friendly; tools require a long time to handle or the functionality is ineffective at supporting the designer's need. A new study might be considered. However our opinion is that the best thing to do is to stop creating other tools and try to understand why these existing tools are not used. The purpose would be to improve them in a way that will encourage designers to use them.

Designers-EOL decision-makers. In the literature studied the authors recognise the importance of considering EOL in the early stage of production. However no link was drawn between the early and late stages of the solution. Suggestions are the following:

(1) For both designers and EOL decision-makers to use the same tools in the early and late stages of production. Whilst, both stages do not need the same specifications, the solution could be to use the same software basis and to add modules in regards to the designers' or EOL decision-makers' needs. Some explanations and guidelines to adapt software can be found in (Frakes, 2005). Moreover, if a common basis is used, it will be easier for designers and decision-makers to understand each other.
(2) To take into account the EOL strategy the product has been designed for, could enable EOL decision-makers to explore the others closely connected EOL options, to determine if they are in fact better suited for the product.

All the actors. Finally a lack of communication between all the actors of the product life cycle was observed. It is less noticeable when the actors are from the same company but it becomes obvious when they are not. Without discussions none of the actors could know the product requirements desired by other enterprises. Actors are not aware of the tools or criteria others use or what kind of preferences or difficulties they have with their processes.

A lot of researchers have suggested data sharing through the Internet. Doing so will enable all the protagonists to have easy and quick access to information, but would never replace regular communication. Moreover (Rose et al., 2002) did more than simply providing access to the data. Through logical reasoning based on yes/no questions, they provide guidelines to follow in case of match or mismatch of the reality with their software results. They provide all the actors with a way to improve the product life cycle together according to their competences as we can observe with the table 4.

Table 4. Efforts needed from product managers, recyclers, and policy makers to improve EOL (Rose et al., 2002).

	Product Management and Development	Recyclers	Policy makers
Match = ELDA classification corresponds to best practice	Reason for discarding, functionality over time, recycling technology, infrastructure	Lower costs, improve yields	Improve efficiency of system
Mismatch = ELDA classification does not correspond to best practice	Internal value chain, consumer, political issues	Find new outlets, talk to producers, talk to organizers of take back systems	Redefine system so that it can handle higher targets

7. CONCLUSION

In this paper the focus was on various ways that could make the recovery process more efficient regarding the necessary information and possible tools that could be used.

First the methodologies that have been created to help the EOL process and the tools that stem from them were identified. Both the early and late stages of production possess tools and software that provide a selection of the best EOL strategies and their assessment. The interest in this domain is wide and a lot of researchers contributed to it. However, if these tools exist they are rarely used in companies. Moreover, the employed tools are often not the same in between the two stages, which leads to wastes of time and money.

We then have underlined the information that is required to evaluate the various solutions suggested in both early and late stages of production, and the ones that might be needed from the different stages to the others. The diverse technologies available to collect, analyse and display the information, was also studied. We found out that the necessary information is known and collected by a performant information system. Unfortunately a lack of communication between all the actors tends to prevent the data sharing.

ACKNOWLEDGEMENT

The work has been carried out within the Production Area of Advance at Chalmers and French Institute for Advanced Mechanics. The research has been sponsored by FFI-VINNOVA. This support is gratefully acknowledged.

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