Abstract— Recycling is a complex activity with long, sometimes unknown and not easily implemented processes. It requires diverse technologies from many fields of application. This sector is marked, on the one hand, by a lack of data, information and knowledge structuring, and a deficiency in management tools and in the sharing of this knowledge, on the other hand. These actors do not have the same understanding of the product, and are facing difficulties to take decisions for an optimal recycling.

This paper suggests a system of information for decision-making assistance for an optimal recycling, applied to the sector of aeronautics for example. In so doing, we first establish a referential product model for recycling, to be used for the conception, utilization and recycling, and then the same model will be integrated in a team work structure. This structure allows a more fruitful collaboration between actors, with the eventual integrating of sundry viewpoints.

Keywords— Recycling; manufactured products; decision-making assistance; system of information; aeronautics.

I. INTRODUCTION

The context of the surge in commodity prices, particularly in Europe and the United States, and of consumers becoming more aware of sustainable development, explains the interest in the recycling industry.

However, recycling appears to be a complex process and sometimes lengthy with little known to develop. Recycling is an activity that promotes the establishment of a network inside and outside the industry. Thus, it incorporates technologies from different application domains, such as construction technology parts and materials, as well as experts from industry, business management of waste, environmental specialists, experts in dismantling, in grinding, sorting, and others. In this context, techniques and procedures used are based on specific knowledge and are diversified [9,10], shared by several branches of sectors both at the level of practical methods and tools. This explains the complexity of the activity, due to the fact that all these businesses must interact for the global optimum: succeeding in a better recycling process while respecting the constraints of each business. Hence, the need for collaboration between stakeholders, in particular to define the recyclability of a particular product, is a crucial issue. This could be solved by the establishment of an organizational memory focused on communication and coordination, in order to provide fast recyclability solutions for different products within the constraints of each trade. For example, suggest the best ways to disassemble the aircraft at the end of life safely and efficiently while ensuring best preserve the value of parts of the plane and meet environmental standards. The remainder of the paper is organized as follows: section 2 describes Recycling Process and constraints. In section 3, we present the existing information systems for valorizing manufactured product at end of life, before proposing in section 4, a Model for System of decision-making assistance for the recycling of manufactured products. This model is reinforced by section 5 of the presentation of the decision-support theory for optimal valorization of the product end of life. Section 6 is devoted to conclusion and perspectives.
II. RECYCLING PROCESS AND CONSTRAINTS

A. Organization of the recycling industry

The recycling activity uses multiple knowledge. It is a long and complex process to achieve the main objective of producing new materials called «secondary» ones [5], [6] and [8].

This sector remains complex in terms of organizational. Because it includes several actors at different levels of intervention on the same product. Indeed, recycling includes areas related to the processing end of product life. Thus, the actors involved in the recycling process are not only the materials recyclers but also the collectors, dismantlers, shredders and other professions in the chain of waste and ecologists or residual rate calculation specialist. These stakeholders work on the same product and are sometimes asynchronous and geographically dispersed, hierarchically and temporally, each with its own knowledge of this product in the same recycling process.

The sector is organized in several hierarchical levels, from collect product to end of life and recycling itself. And each actor at his level can take decisions that affect all the levels

B. Recycling activity

This pattern (Fig. 1) of recycling activity is more or less the same, at least at the base, wherever the activity takes place) [5, 7]. The product at end of life undergoes a pretreatment, i.e. the separation which is done by sorting materials and recyclable fluids and putting aside everything that is not directly recyclable. The remainder undergoes other treatment also as part of the recycling process, or they are crushed or incinerated. However, the goal, as is illustrated in the figure is to increase the value of «X» which is the rate of recovery, while trying to reduce to zero the value of «Y» which corresponds to the rate of waste [5, 7].

The implementation of this activity in full force needs the competences of several actors. Thus, it uses shared knowledge: the knowledge related to the product and the knowledge related to the process of dismantling, disassembly, sorting, etc., and at last the knowledge for the waste management, marketing of recycled products, etc.

Indeed, we need a good command of the manufactured product to be recycled, which is complex, both in its composition at the level of technology used in its manufacture. This would simplify the disassembly; reduce the time needed to identify the materials that compose it, minimize and isolate the non-recyclable, to increase the recoverable products, thereby increasing the benefits of recycling. It is to maximize «X» (X=recovery rate) or minimize «Y» (Y=rate of waste) [5, 7].

III. EXISTING INFORMATION SYSTEMS FOR DECISION SUPPORT FOR THE VALORIZATION MANUFACTURED PRODUCTS AT END OF LIFE

There are information systems that operate more specifically on two aspects: either to give information to the environmental impact of the product that has reached the end of its life, or to provide information to recyclers on that product (i.e. what would be made with the product that has reached the end of its life?). But none of these systems go into the details of recycling the same way proposed here.

Ajith and al. are clearly identifying the different types of information systems existing around the product in their paper. Also, they have proposed a model of information system center around the product. However, like other authors, they provide systems for decision support at the end of product life [1], [10], [11] and [13].
These systems are divided into two categories [1], [10], [11] and [13].

- Design and disassembly data sharing systems,
- Lifecycle information monitoring systems.

The design and disassembly data sharing systems are designed with the sole purpose of providing them to the recyclers. At present, none of the systems are capable of providing accurate information about the state and structure of the product at its end-of-life, because they fail to incorporate changes throughout the product’s lifecycle and the associated external information required for making decisions at end-of-life.

The lifecycle data monitoring systems classify information into the following categories:

- Static classes, which include design and disassembly information;
- Dynamic classes, which include performance parameters that affect end-of-life decisions.

The major drawback of such an approach is that it fails to capture the dynamic nature of the so-called ‘static’ information. For example, it is unable to incorporate changes inflicted by the production process on the design of the product. In addition, it fails to integrate necessary external information (legislation, corporate policies, etc.) that is required for making effective product recovery decisions. This results in the inability of these systems to provide accurate information regarding the status of the product at end-of-life, thereby failing to provide sufficient support for end-of-life decision-making [5, 7].

Therefore, we find that at present, there is no information system for decision support that deals comprehensively with all the requirements, the end of life of manufactured goods. Thus, taking into account the limitations of these systems, we propose an approach centered on the product, and focused squarely recycling.

IV. MODEL FOR SYSTEM OF DECISION-MAKING ASSISTANCE FOR THE RECYCLING OF MANUFACTURED PRODUCT

In this section we propose an organizational model for recycling, but first we review the structure of the manufactured product and propose a model related to that structure.

A. Structure of the Manufactured Product and model of product for recycling

A product is a number of components linked together by fasteners. A component consists of a number of sub-components or parts held together by fasteners. A piece is a certain amount of material that has a particular shape [5,7].

In UML formalism, this pattern can be represented as depicted in Fig. 2 below:

![UML Product Class Diagram](image)

Fig. 2. UML Product Class Diagram [2, 3].

Fig. 2 shows the class diagram of the product model. The stakeholders will describe all product information in terms of function, structure, and behavior to better understand the different perceptions that exist around the product.

Indeed, in its lifecycle, the actors perceive the product in different ways. For example, the designer and recycler do not necessarily share the same view for the same product. Notably, the designer has a functional view on the product, contrary to one who dismantles the product and has a material-oriented view.

The connections between components are modeled in Fig. 3 with the types of binding, number of links, structure, etc., which are important characteristics for dismantling or separation of materials.
B. Semantics matrix

Table 1 shows a semantic matrix describing a product consisting of components \( C_i \), with features and assembly connections \((C_i, C_j)\). This matrix is filled from design data available in the CAD system to which we add semantic features. The diagonal elements of the matrix \( P_i \) contain specific data component \( C_i \) (geometry, material properties, tolerances, ...) while the terms between the two components \((C_i, C_j)\) describe the types of mechanical connections (welding, bolting, riveting, ...) (see Table 2) [2], [3] and [4].

**TABLE I. SEMANTICS MATRIX OF A PRODUCT [2], [3] AND [4]**

<table>
<thead>
<tr>
<th>Components</th>
<th>( M_1 )</th>
<th>( M_2 )</th>
<th>( - )</th>
<th>( M_j )</th>
<th>( - )</th>
<th>( - )</th>
<th>( M_p )</th>
<th>Reliability</th>
<th>Criticality</th>
<th>Recyclability</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_1 )</td>
<td>( P_1 )</td>
<td>2 0 1 0 1 5 2 0</td>
<td>( F_1 )</td>
<td>( K_1 )</td>
<td>( R_1 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( M_2 )</td>
<td>( P_2 )</td>
<td>2 1 0 0 0 0 2 0</td>
<td>( F_2 )</td>
<td>( K_2 )</td>
<td>( R_2 )</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>-</td>
<td>-</td>
<td>0 0 0 0 2 0</td>
<td>-</td>
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<td>-</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>-</td>
<td>-</td>
<td>1 0 2 0</td>
<td>-</td>
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<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( M_1 )</td>
<td>Type of connections</td>
<td>Type of connections</td>
<td>1 0 2 0</td>
<td>( F_i )</td>
<td>( K_i )</td>
<td>( R_i )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( M_2 )</td>
<td>( M_1 ) =( M_1 )</td>
<td>( M_j ) =( M_j )</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>2 0</td>
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<td>-</td>
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<td></td>
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<tr>
<td>-</td>
<td>-</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( M_p )</td>
<td>( P_p )</td>
<td>( F_p )</td>
<td>( K_p )</td>
<td>( R_p )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of connections</td>
<td>( d_1 )</td>
<td>( d_2 )</td>
<td>( d_j )</td>
<td>( d_p )</td>
<td>( F_0 ) (threshold)</td>
<td>( K_0 ) (threshold)</td>
<td>( R_0 ) (threshold)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE II. TIMELINE OF DISMANTLING/ASSEMBLY ACCORDING LINK [2,3]**

<table>
<thead>
<tr>
<th>Connection types</th>
<th>Timeline of Dismantling/assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without contact</td>
<td>0</td>
</tr>
<tr>
<td>Contact</td>
<td>1</td>
</tr>
<tr>
<td>Clipping</td>
<td>2</td>
</tr>
<tr>
<td>Screwing</td>
<td>3</td>
</tr>
<tr>
<td>Bolting</td>
<td>4</td>
</tr>
<tr>
<td>Box</td>
<td>7</td>
</tr>
<tr>
<td>Collage</td>
<td>8</td>
</tr>
<tr>
<td>Riveting</td>
<td>6</td>
</tr>
<tr>
<td>Welding</td>
<td>10</td>
</tr>
</tbody>
</table>

As part of the value of the product and its components, the matrix is enriched with additional data such as recyclability (\( R_i \)), the environmental impact of recycled components, or with data reuses conditions.
Thus it will be possible to include in the base product all the information on the product data (type and composition ...), data related to end of life option, disassembly data, materials and data connections, economic data (cost disassembly, recycling, resale, environment ...)

The key points of our approach are collaboration, communication and sharing a common vision, which allows actors on the product throughout its life cycle to understand and access the knowledge that they need. Thus, after describing the sub-product model, we propose a model taking into account the entire recycling industry for dynamic management of business rules for the collaboration of different actors. To do this, we will refer to the PPO model to define a common model that should exist for recycling [12] and [5]. It includes sub-models’ product, process, and organization.

C. Organizational model of recycling framework

In this part, we propose a model that intends to take into account all of the recycling industry for dynamic management of business rules for the collaboration of different actors. To this aim, we will define a common model that should exist for recycling, based on the PPO (Product-Process-Organization) model. It includes sub-models product, process, and organization, taking into account the objectives, standards and constraints, criteria of recyclability of a product and the difficulty in sorting, that is to say, integrating business rules.

The PPO model inspires the model we propose. The PPO model has been developed under the project IPPOP [20]. It is the result of three models: a product meta-model, process meta-model and an organization meta-model. This is a light and scalable meta-model. Thus our model as the PPO model has two main features [12]:

- It is a simple model, which deals with basic concepts for modeling. Its diagram class (Fig. 5) shows: (i) four non-abstract classes for defining the product: the Product class, Component class t, Part class and sub-assembly class, (ii) five non-abstract classes for the definition of project planning recycling: Procedure class, the human class, Hardware class, Software class and Information class, (iii) three classes are used to define the organization and capabilities of the company: Center Decision class, Recycling Framework class and the Decision Framework class. The three sub models (Product, Process and Organization) are mainly built around the project class,

- A scalable model, it is possible to specialize to be a language for sharing and exchanging information throughout the process of product development. Each expert can complete all the attributes of each class of models in Product, Process and Organization for a detailed description of the whole model and adapted to its needs of sharing,

- This model is composed of three parts that can be called sub-model: part product, part of the organization and between the two part processes. Each of these parts is represented using basic entity for example, function, structure and behavior for the product.

Fig. 4. Recycling Classes Diagram (based on PPO model) [5], [12]
V. THE DECISION-SUPPORT THEORY TO MAXIMIZE THE RECYCLING RATE

In the spirit of maximizing the recycling rate "X", we introduce in this part the concept of the theory of decision. Indeed, optimization and maximization are the keywords defining the theories of decision making based on rationalization, that is to say, the theories defining the logical and rational standards that all decision makers are expected to follow that the choice is the one who "reported" the most. The theory of expected utility (EU) is the most common approach used by decision theory to describe the choice [5] and [14].

Either ξ information obtained by an expert to make a decision on a product reaches the end of life. The information includes all information held, known to be true to the base or deducted from logic, as well as frequent information, returning often.

Let p(H | ξ), which represents the probability (or belief) that the hypothesis posed H is true.

The principal MEU (Maximum Expected Utility) enunciates that we must take action that increases the value calculated by adding all the values (Expected Utility) assigned to each possible outcome multiplied by the probability of this outcome.

Let H the random variable representing the state of a product, ΩH all n possible states of the product, that is to say ΩH = {h1, h2, ..., hn}, p (H \ ξ) the probability distribution on the different product statements in the decider, D a set of possible options for product recovery, and the whole

\[ u_ξ : h \times d_i \rightarrow u (h_i, d_j) \]

represents the value of the d option when choosing product status is hi. Then the expected utility (EU) of a d option is given by:

\[ EU(d_j) = \sum_{i=1}^{n} p(h_i | \xi) u(h_i, d_j) \]  

(1)

The states of the product might be the ratings of the product based on its quality, or simply a binary state representing a good or bad product. The utility u(Well, re-use) could be for example the sale price, if the decision is to reuse the product because the product is good. In cases where the products are to be refurbished before resale, the utility must include the costs involved in renovation too.

Given the probability distribution and the utility model, the best decision D * is given by (2)

\[ D^* = \arg \max_{d_j} \sum_{i=1}^{n} p(h_i | \xi) u(h_i, d_j) \]  

(2)

Obviously, Equation (2) gives the product recovery option with the greatest EU based on the belief of the decision maker on the state of the returned product and is a formal representation of the MEU principle.

The expected maximum utility (or planned) EU * is given by (3)

\[ EU^* = \max_{d_j} \sum_{i=1}^{n} p(h_i | \xi) u(h_i, d_j) \]  

(3)

Equation (3) gives the MEU make an immediate decision, prior information. We can then interpret EU * as an indicator of the perceived value of the product based on the belief of the decision maker on the state of the product [9] and [22].

VI. CONCLUSION AND PERSPECTIVES

In this article we focus on the issues of decision for an optimal recycling of manufactured products at the end of life. Indeed, recycling is complex due to the fact that processes are long and sometimes not mastered. In addition, multiple actors involve on the same product in a sector where data are not necessarily structured. Whereas, the tools and methods used do not provide more opportunity for an optimal recycling according the constraints around the process. Therefore, we propose a model based on the product, integrating the three sub-models Product, Process and Organization, to improve collaboration of actors. Our proposition facilitates very fast proposals recyclable solutions of different products according the constraints of each trade. In addition, it facilitates the acceleration of the process of restitution of information following the collaborative interests of the actors, and also to link the knowledge of different stakeholders. We have also, in addition to our model introduced a theory of support decision for an optimal choice of the development of the product. In fact, this work opens the way to solve a problem that has never been totally treated in the previous work. Various models to solve this problem were limited to a macroscopic level in the product design or projections on the processing of products at the end of cycle. In our
future works, we plan to consolidate our work by applying it in the recycling of aircraft. Bombardier in Canada and Airbus in France has initiated similar projects. This would help also to identify other benefits and not yet recognized limits.

REFERENCES


BIOGRAPHY

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