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DECISION AID TOOL AND DESIGN APPROACH FOR PLASTIC RECYCLING CHAIN INTEGRATION IN THE AUTOMOTIVE INDUSTRY

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ABSTRACT
The many uses of plastics in our society are now compromised because of the social and environmental impacts they generate: exhaustion of petroleum resources, waste management... Plastics recycling appears to be one of the best ways to solve these problems. But Plastics Recycling Chains (PRC) are still emerging system. The automotive industry is directly concerned by plastic recycling through the End of Life Vehicles (ELV) directive which compels it to respect recycling rate for their products and to increase the use of recycled materials. But at present the use of recycled plastics in this industry is strictly limited to low-quality products. Main reasons for this situation are that recycled plastics' characteristics are often underestimated and can differ importantly from one supplier to another and also in time. It results in a lack of confidence in PRC's capabilities. In order to increase the recycled plastics' rate in new vehicles, especially in high-quality parts, PRC must respond to the supplier selection criteria. This implies that PRC must supply large quantity of high-quality materials with stable properties. As many stakeholders will be involved in PRC's efficiency, we have built a dynamic model of these PRC, named ODEFIRE, to determine in which technical and economic conditions they might better satisfy the automotive industry requirements. On the other side, we have also developed for the automotive design departments an approach called DAIMRE based on accumulation of knowledge of recycled plastics' characteristics and PRC's capabilities which are, for a part, fed by ODEFIRE simulations.

Keywords: Plastics recycling chain, reverse supply chain, automotive industry, flow management, recycled plastic use

1 INTRODUCTION
The predominant use of plastics in everyday life may be legitimately reconsidered because of their social impacts (chemical rejects), their environmental impacts (exhaustion of petroleum resources, waste management) and also legislative pressures [1]. Efficient solutions have now to be implemented to go toward more sustainability. Material recycling appears to be the best response to solve environmental problems generated by plastics. However, Plastics Recycling Chains (PRC) are still emergent [2] and their economic actors fail to make profits. Two major reasons explain this situation: plastic waste flows and consequently recycled plastics ones are discontinuous and demand for recycled plastics remains low. This phenomenon is self-maintained and impacts directly the automotive industry [3] as an increasing user of plastics and consequently a potential user of recycled plastics. Indeed, the End-of-Life Vehicle (ELV) directive [4] (recycling rate of 80% for 2006 and 85% for 2015) compels car manufacturers and consequently their suppliers to develop viable end-of-life scenarios and to give information on scenario efficiency. The effective recycling rate is currently inferior to 80% for present ELV that contain a high proportion of metal. In new vehicles, manufacturers use a higher proportion of plastics, so we can fear that the recycling rate might reach a lower value if the present technical and economic conditions of PRC do not change. Indeed only a few part of automotive plastics is recycled for example in France (4,7% of the plastics used in the French automotive industry is recycled and 8% of the plastics used in the European automotive industry) [5]. So as metal recycling is already optimised, achieving the directive's objectives requires an increasing in the rate of plastic recycling. To reach this purpose is still a major problem in France because the

existing PRC are not technically and economically adapted and are characterised by a poor running and a lack of economic value [6]. One way of facilitating PRC's development is to provide high-value markets to recycled materials. It will also aid the automotive industry to achieve another requirement of the ELV directive [4]: to increase the proportion of recycled plastics used in vehicle design. Only 3% of recycled plastics from post-consumer waste are currently used in new automotive products and only in low-quality ones as wheel arches [7]. Using recycled plastic in high-quality products as structural parts is not a common practice. Consequently, there are two main objectives in our research [8]:

- To contribute to automotive PRC's development. The PRC's situation must evolve from an emerging to a stable one in order to ensure a quantity, a quality and a price of recycled materials meeting the automotive industry specifications
- To develop an approach to increase the use of recycled plastics in the design of high quality applications and to make this use a common practice.

Reaching these objectives signifies to take into account product design, the choice of an end-of-life scenario and the use of a recycled plastic at the same time. This implies to integrate PRC into the automotive supply chain in closing the recycling loop (Figure 1).

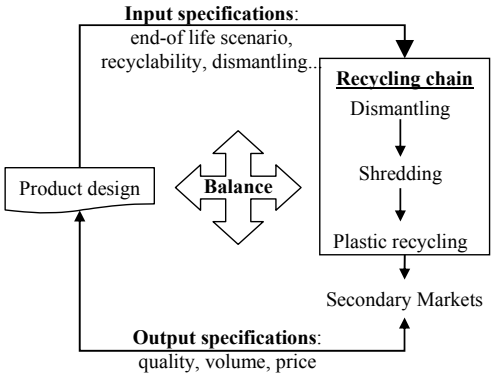

Figure 1: PRC's integration in the automotive supply chain

In the first section, we shall set out the reasons why the use of recycled plastics is not a common practice in design. These main ones are the no integration of recycled plastics in ecodesign tools, the human barriers as the lack of knowledge of PRC's characteristics, the technical and industrial risks due to the imbalance between automotive specifications and PRC's capabilities... Examination of this synthesis leads us to state the need to implement an approach based on changes in ecodesign practices, the integration of knowledge of PRC's capabilities in existing databases. From this analysis, we also conclude that PRC's situation is such complicated that only a systemic approach has any sense if we are to be able to suggest action for making changes to it.

This observation leads us to develop a dynamic model of the interactions between PRC's actors ("ODEFIRE"[1]) presented in a second part. This model enables us to analyse effects of quality, quantity and cost modifications of recycled plastics. The results authorize stakeholders (recycling companies, dismantlers, automotive industry society) to better know the real and potential PRC's capabilities, to better anticipate the consequences of future changes as virgin material price increase and recycled material demand increase…). They will also aid each stakeholder to make the right decision with respect to all stakeholders' expectations. The model structure and the main results are described in the following sections for the case of a regional recycling chain of PP from bumpers. This model is also a supplier of information on PRC's capabilities in order to facilitate the use of recycled plastics in automotive supplier's design.

In the last part, we describe the approach "DAIMRE"[2] developed to encourage the use of recycled plastics in design. DAIMRE is centred on acquisition of knowledge of recycled material characteristics and PRC's capabilities by each project team member. This acquisition is obtained by

[1] Decision aid tool for PRC's development, "Outil d'aide à la Décision pour le suivi de FIlières de REcyclage de matières plastiques"

[2] Approach for the integration of the use of recycled plastic by knowledge acquisition, "Démarche d'Acquisition de connaissances formelles et informelles pour l'Intégration de la Matière REcyclée en conception ».

databases fed by ODEFIRE. This approach is also based on the approval of the recycled plastic and on the assessment of the balance between high-quality part specifications and technical and economic capabilities of the PRC associated (solvability, material characteristics in terms of quantity, quality…), realised by ODEFIRE. This assessment leads to calculate a recycling mark standing for the possibility to use a recycled plastic in design with a minimum of risks. This part of our work was developed in partnership with POAE[3] [9]. The use of this approach in structural part design at POAE and its results are detailed in the final section.

2 BARRIERS TO RECYCLING CHAIN INTEGRATION IN THE AUTOMOTIVE SUPPLY CHAIN

Even if some car manufacturers have shown that using recycled plastics in structural parts is possible without property losses, it appears that they don't require their part suppliers to use a specific amount of such material in their high-quality products. We will explain the reasons of this situation in the next sections.

2.1 Usage barriers in automotive design

Literature review [1-10-11] and discussion with project team members (designers, material and quality experts, purchasers) [8] revealed two main types of barriers to the use of recycled plastics from post-consumer waste in the automotive supplier's design practices: human and organizational barriers.

The human ones correspond to resistance to changes of common design practices and are due to:

- The fact that the automotive supplier does not regard himself as a potential user of recycled plastics.
- The poor image of this material compared with virgin one. A product designed in recycled plastic is still perceived as being a poor quality product by designers and other project team members [10].
- The lack of confidence in material properties considering the emerging situation of recycling chains and also in the ability of recycling industries to produce materials meeting automotive specifications in terms of quality, volume and price. This behaviour is reinforced by a lack of knowledge of material characteristics and especially of the performance of the corresponding PRC.
- The lack of environmental awareness of plastic recycling challenges (resource saving, waste reduction).

This use is also restricted by organisational barriers as:

- No integration of recycled plastics in the early stages of the design process as for virgin one [11]. It signifies that there is no recycled material approval making this material into an available reference in the material database used in design. Indeed recycled plastics are often used directly in production plants in order to reduce costs. It implies that injection moulds are not designed for such material but for virgin one. These practices result in variations between part simulation and production results due to differences between virgin and recycled material properties and their parameters setting. This can be synonymous of material shrinkage and production stoppage.
- The design of only 100% recycled parts (parts made only with recycled plastic) limiting their use to low-quality products. To face this problem, it has been shown that the use of a material with a recycled content of 20% (a recycled compound) allows the production of a material without property losses compared to virgin ones [1]. But this practice is not well-accepted by designers and production operators because of the technical changes of the production tools induced by the use of a recycled compound.

The last barriers concern ecodesign tools and the non consideration of the use of recycled plastics in such tools. Many ecodesign tools and methods were implemented by car manufacturers and their suppliers in order to obtain a real harmonization between design specifications and capabilities of present or potential end-of-life treatments [12-13-14-15-16]. They include rules (material choice, fastening choice), dismantling guides, tools (design for recycling), recyclability criteria (depending on weight, costs...)…. Concerning material choice, these tools notably aid designers to choose recyclable,

[3] Plastic Omnium Automotive Exterior

renewable and compatible materials to facilitate recovery. They also allow them to determine the amount of recycled material used in the product. But these tools don't:

- Allow to consider the becoming of the recycled plastic produced by the recycling scenario encouraged by designers through their design choices (a possible use in the initial product).
- Supply sufficient information on technical and economic capabilities of PRC inducing human barriers.
- Facilitate the use of recycled plastics in design

All these barriers reveal that encouraging the use of recycled plastics, notably in high quality products, passes through the implementation of a quality approach authorizing to:

- Define the changes to make to reach recycled plastic approval
- Complete ecodesign rules in combining end-of-life scenario choices with the use of the recycled plastic produced by the scenario in automotive design.

2.2 Recycling chain capabilities versus automotive industry specifications

In spite of the ELV directive objectives, car manufacturers don't currently add specific requirements for the use of recycled plastics in their design specifications except for the French car manufacturer Renault. Therefore developing this use in high-quality products supposes that automotive suppliers as our partner POAE, will have to anticipate the future demand from the car manufacturers but also to aid recycling companies able to provide the right recycled materials, to evolve to a viable situation. There is not a keen interest in this use because the production of recycled plastics does not open a new market; it takes over a share in the virgin material market. Moreover virgin material is not so expensive and presents a perfectly controlled quality. Recycling companies are also faced to industrial companies which produce virgin plastic, provide guarantees of material properties and have production practices very different from those used by recycling companies. Consequently, faced to virgin material producers, it is difficult for recycling actors to meet all the supplier criteria required by the automotive supply chain (solvability, volume and quality required for one project).

The imbalance between recycling companies and automotive specifications can be explained by [8]:

- **Technical limit**s: their activities are not coordinated around specific grades of recycled materials characterised by stable volumes available on the market. Indeed, because of the diversity of the sources and qualities of end-of-life materials, they meet problems to produce grades without properties fluctuations. Recycled plastics are essentially produced from a mixture of various materials whose quality is often unknown. This induces problems of traceability and follow-up to recycled materials quality. The poor level of maturity of recycling companies and their lack of mastery of material formulation is not consistent with the level of quality required to be included in the panel of automotive suppliers.
- **Economic limits**: most recycling companies are not viable structures because of the lack of high-value markets and especially the lack of end-of-life plastics inducing high production costs.
- **Organizational limits**: recycling companies are often little firms, unstable structures faced with a supply chain including large companies and a complex organisation of suppliers. Moreover they don't have robust contractual relations between them. Consequently they are confronted with a great variability of the end-of-life flows they can treat. There is also a lack of professionalism characterised by a lack of coordination with the other PRC's actors. There is not a relation customer-supplier as in a supply chain [10]].

Faced to the persistent emerging situation of recovery chains in general, various models were developed in order to identify the main barriers to PRC's development. The most important barriers are those which prevent PRC from reaching a financial equilibrium corresponding to a positive margin for each PRC's business. A literature review [8] indicated that three forms of research are usually undertaken to understand recycling chains behaviour:

- Research on recycling processes [17]
- Research on the design of recycling chains, [18-19]
- Research on the technical and economic characteristics specific to one or more businesses in the chain, [20-21]

This review combined to an analysis of quantitative models revealed some limits and lacks [18-22-8]:

- These approaches do not take into account the specificities (capabilities in terms of quantity,

quality, different maturities, conflicting goals) of each actor (dismantler, shredder and recycling companies) involved, and the fact that the businesses are especially small-scale companies.

- They don't consider all the operators from the last owner to the market including the supply chain. They don't use a global systemic approach (for example they just study dismantler, shredder but not recycling companies [21]). Recycling companies are not seen as potential suppliers for the automotive market.
- Few consider the evolution of existing chains and try to find the reasons for their poor development.
- They analyse the effect of product design on recycling chains but not the becoming of the recycled material and its consequences on the chain.

All this explains why PRC can't reach the automotive market specifications for high-quality products. Encouraging recycled material use passes first through a structural evolution of recycling companies and then through an evolution of the design practices of car manufacturers and their suppliers.

In conclusion, the use barriers in design and the inadequate capabilities of recycling companies make the use of recycled material in high-quality products a use with serious risks. Ways to minimise these risks must be implemented. Moreover, encouraging PRC's development by using recycled plastics in structural parts design appears to be the decisive factor in the implementation of a real ecodesign policy for plastic components. To reach these purposes, we propose to:

- Create a dynamic model of PRC (ODEFIRE) based on a systemic approach taking into account effects of interactions between all businesses (from dismantler to market). This should allow us to identify major causes of their emerging state, whether actions can be undertaken to develop them and by whom.
- Implement an approach to standardize the use of recycled plastics in automotive high quality products, approach based on the acquisition of knowledge of recycled material specificities and recycling chain capabilities (DAIMRE) through the use of ODEFIRE.

3 ODEFIRE: A DECISION AID TOOL FOR RECYCLING CHAINS DEVELOPMENT

3.1 Model construction

3.1.1 Objectives

The literature analysis revealed that only a systemic approach can traduce the PRC's complexity and has any sense to determine the actions necessary for PRC's evolution. PRC's actors and stakeholders concerned by such systems and their expectations are:

- PRC's operators who need to identify their development opportunities in order to decide on the investments which they could and should make in order to obtain an economic equilibrium.
- Automotive suppliers who need to know the PRC's capabilities to produce a recycled material corresponding to their specifications.
- Car manufacturers who need information about PRC's capabilities in order to establish the capacities of their vehicles to satisfy the regulatory requirements.
- Society who must have the ways to appreciate the effects of aids it gives and also if constraints it imposes on the various businesses.

To find answers to these questions, we created a dynamic model of the flows of the existing PRC including all stakeholders. By dynamic modelling, our aims were to:

- Analyse the technical and economic behaviours of PRC's operators by measuring their performance in terms of financial margin, material quantity, quality and price.
- Model the interactions between operators in order to identify the actions to conduct by each business.
- Identify the technical and economic parameters that have a decisive effect on PRC's stabilisation.

The final result expected is the proposition of development specifications for each business answering all stakeholders' needs.

3.1.2 Structure

To create the model, we used the program Witness@. The evaluation of the interactions between actors and of their variability is carried out by modelling the material (product, quality, quantity, source…) and economic (production cost, selling price) flows passing through the PRC. The stages of treatment realised by each business are defined by technical and economic characteristics (treatment capacity, effectiveness, maintenance costs…). The value of each flow characteristic is quantified from literature completed by questionnaire surveys. We will not detail in this article the construction of the model, construction presented in [8-23]. We will present the main stages of the experiment necessary to define business' specifications as well as the main results obtained for the PRC chosen (Figure 2).

The model authorises us to assess present and future economic and technical performance of PRC. A performance is multidimensional, multi-criteria and also multi-businesses. Performance characteristics and the expected value depend on the needs of each stakeholder involved. In our experiment, a performance is defined by performance indicators which were translated into model's parameters. Our model assesses the value of the indicators according to the values of the PRC's characteristics which are modified in changing the values of the model parameters. Then the indicator value obtained is compared to the value expected by stakeholders (Figure 2). If there is a difference between these two values, we search to annihilate this difference by modify well-chosen parameters of the model and then we define actions allowing this modification. Among the indicators recorded, the overall margin of the PRC and of each of the businesses appear as a recurring and dominating indicator and stands for an overall measurement of the stability of the system. Indeed, the value of the margin is linked to many other indicators both technical and organisational. In other words, a positive financial result for the various businesses is a necessary condition for the emergence of the PRC. The respective profit margins of the PRC's businesses are variables which we have sought to maximise in our model.

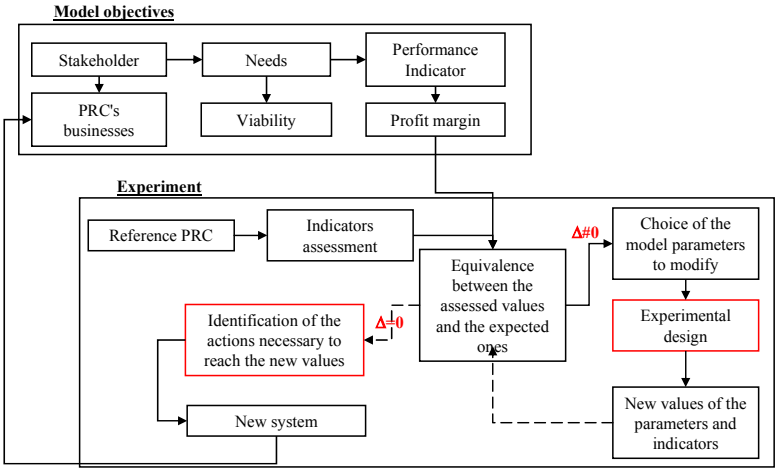

Figure 2: Stages of the model experiment to achieve stakeholders' expectations

3.2 The PRC modelled and results

3.2.1 The bumper recycling chain

We modelled a PRC capable of producing recycled Polypropylene (PP), the most widely used plastic in vehicles. The recycling chain has been considered on the scale of a French region. This model was developed with the support of POAE. POAE was interested in knowing if such a chain could produce a high quality grade as PP reinforced by glass fibres (GF-PP). In order to respond to this demand, material sources of high and well-known quality had to be found in order to facilitate the GF-PP production and to give all the ways to insure material properties stability in time. That's why we analysed the consequences of providing a new type of end-of-life material, bumpers. Bumpers were chosen because of several specific characteristics:

- They are the largest plastic component on vehicles and dismantling them is relatively easy;
- Some dismantlers already dismantle them to reach other parts to which they block access, but they do not give them for recycling as they do not know of its existence
- Their quality is known and sufficient to produce recycled GF-PP.

The activities taken into account in this recycling chain are**:**

- Collection of end-of-life vehicles (ELV) and accident damaged vehicles (ADV).
- Dismantler's activities:
  - demolition activities: depollution of vehicles, dismantling and sale of second-hand spare parts, dismantling of bumpers, sale of vehicle shells to scrap metal dealers;
  - sideline activities: repair and sale of second-hand vehicles and of insurance vehicles.
- Shredding and collection of bumpers from dismantlers: shredding is performed by dismantlers.
- Recycling company's activities: grinding and washing of PP components, material homogenization, extrusion/granulation with resin formulation.
- Sale of the recycled material to automotive plastic suppliers.

3.2.2 Stakeholders' specifications and actions

The objective of this model is to determine if the selected PRC can achieve stakeholders' expectations as POAE's ones and what are the corresponding specifications for each business (Table 1, Table 2). Table 1 summarises the responses of the optimised model according to the expectations of the automotive industry and of the recycling chain operators. Table 2 gives the specifications that must respect each actor and the stakeholder in charge of the specifications implementation. The model succeeded in giving the main actions to implement in order to reach financial equilibrium (Table 2). These results correspond to the ideal conditions for the PRC according to the objectives expected [8]. The proposals summarised in Table 2 underline that a profit margin for PRC's operators can be obtained in return for action. However it must be noted that the equilibrium created could only be achieved by considering two essential conditions:

- an increase of 20% in the virgin material price relative to its price in 2004 (constant euros)
- supplying the recycling company with more good quality PP waste.

Having resolved these two aspects, various actions should be envisaged:

- increasing the cooperation between businesses to identify new flows of material,
- making their relationships contractual to sustain these flows of material in the long term,
- the industrialization and/or grouping together of dismantler,
- modification of activities (adding reformulation skills to those that recycling companies already have, working on integrating recycled materials into design project procedures),
- positioning recycled materials on high added value markets
- encouraging opening the automotive market to recycling companies to allow their development and thus get them onto the list of suppliers.

We can conclude that the chain can fulfil automotive specifications and that producing a high quality reference aid it to reach equilibrium. But proving the actions presented is not sufficient to reach a stable situation for PRC, automotive supplier must implement an approach to integrate the use of recycled material in the design of high quality products. The model presented can give the necessary information to evaluate the possibility to use a recycled material and can also be a supplier of information on recycling chain capabilities and a first step to standardize the use of recycled plastic.

4 DAIMRE: AN APPROACH BY KNOWLEDGE ACQUISITION WITH ODEFIRE

4.1 Structure

4.1.1 Principle

The approach "DAIMRE" is specific to the use of recycled plastics in the design of structural parts at automotive supplier's. What is important is the changes to adapt the use practices for the virgin material to the recycled one. This can be obtained in giving to the right persons the right knowledge of the recycled material characteristics and the PRC's capabilities to produce such material. This last information will be fed by ODEFIRE. The creation and acquisition of such knowledge will minimise the technical and economic risks directly linked to the present use practices of recycled plastics.

The ways we propose to provide this knowledge for designers and project team members are:

- The implementation of a recycled material sheet including information on recycling companies

(name, number, material grade...) and on the present and potential technical and economic capabilities of the PRC (volume, quality, price…) (information fed by ODEFIRE)

- The assessment of a recycling mark standing for the possibility of using each recycled plastic in design based on the evaluation of the balance between material characteristics and PRC's capabilities.
- The development of a recycled compound (in collaboration with recycling companies) in order to break human barriers and the resistance to change from project team members.

In order to fulfil these requirements, our approach is composed of three main steps:

- The recycled material approval: implementation of a sheet considering the material, the supplier and the part associated
- The organizational changes of the design practices to adapt existing tools to recycled material.
- The standardisation: integration of the new knowledge in the existing tools and ecodesign rules changes (with ODEFIRE).

We will detail here only the last step of the method. The other steps were developed in [24-8].

Table 1: Contibution of the modelled PRC to fulfil stakeholders' objectives

Stakeholders	Objectives	Values
Car manufacturers	Viability of ELV recovery chain : no financial support	++
	Choice of the right end-of-life scenarios	-+
	Information on performance for decision-making in design	++
	Respect of the legislation objectives	+
	Increase of recycled plastic use	++
Automotive suppliers	Recycling companies as supplier	++
	Increase of the use of high mechanical performance recycled material in design	+
	Recovery solutions for their parts	+
	Forecast car manufacturers' demand	++
	Potential performance of recycling companies	++
Recycling chain businesses	Viability	++ (Margin>>0)
	Increase of inputs and outputs	++
	New high quality recycled plastics	++
	To find the right organization	-+

Table 2: Actions proposal for stakeholders (++=completely reached, +=partially reached, +-= insufficiently reached)

Stakeholders	Actions
Recycling company's specifications	
Automotive industry, Society	Recycled plastic price increase linked to virgin material price increase
Automotive industry, Recycling company	Production of high quality recycled plastics= new outlets
Automotive industry, Recycling company, Dismantler	Treatment of new sources (new parts, new material)
Recycling company, PRC's actors	Sources number increase
Recycling company, Dismantler, Society	Low price material
Dismantler's specifications	
Dismantler, Automotive industry	New recycling activity (bumper dismantling) or dismantling industrialization
Dismantler, Society	Decrease of the ELV (from insurance companies) number Decrease of spare parts dismantling
Dismantler, PRC's businesses	Body shell weight and price increase

4.1.2 Ecodesign rules modification

This last stage of the approach is detailed in Figure 3. We can note that ODEFIRE plays several times a role in the accumulation of the knowledge of recycled material. First it is used to implement a database of PRC's capabilities in order to:

- feed the specificities of the recycling companies capable to produce the wished materials.
- complete the existing ecodesign rules giving a recycling mark. This mark stands for the present possibility to use a recycled material in design (not the theoretical possibility) [8]. It is one of the original changes of our approach. It also stands for the final step of the material approval. In fact according to its value, the chosen material will be associated to the material database or not.

The main steps of the assessment of the recycling mark are detailed in Figure 4. This mark corresponds to the evaluation of the balance between the values of recycling criteria obtained for one recycled plastic (Table 3) and the values expected by automotive project members. The chosen criteria are representative of the existing situation of PRC but also of their adequacy with specifications and supplier criteria required by the automotive supplier. The choice of the criteria, their values and weights are fixed from discussion with designers, material and quality experts (directly concerned by the use of recycled materials) and literature review [8]. The criterion "potential" is fed by ODEFIRE. The intermediate marks are weighted according to the impact of each criterion on the possibility to use the recycled material. The final mark is the result of the combination of the final marks of each criterion. The recycling mark varies between 1 and 5:

- 3,5<Mark<5: the material can be used without major risks
- 2,5<Mark<3,5: the material can't be used without risks. A more accurate analysis can be conducted to find possibilities to minimise these risks.
- Mark<2,5: the material use is impossible without important changes. It can signify that the PRC doesn't exist or doesn't have the capabilities to produce the recycled material or that the material is not adapted to recycling.

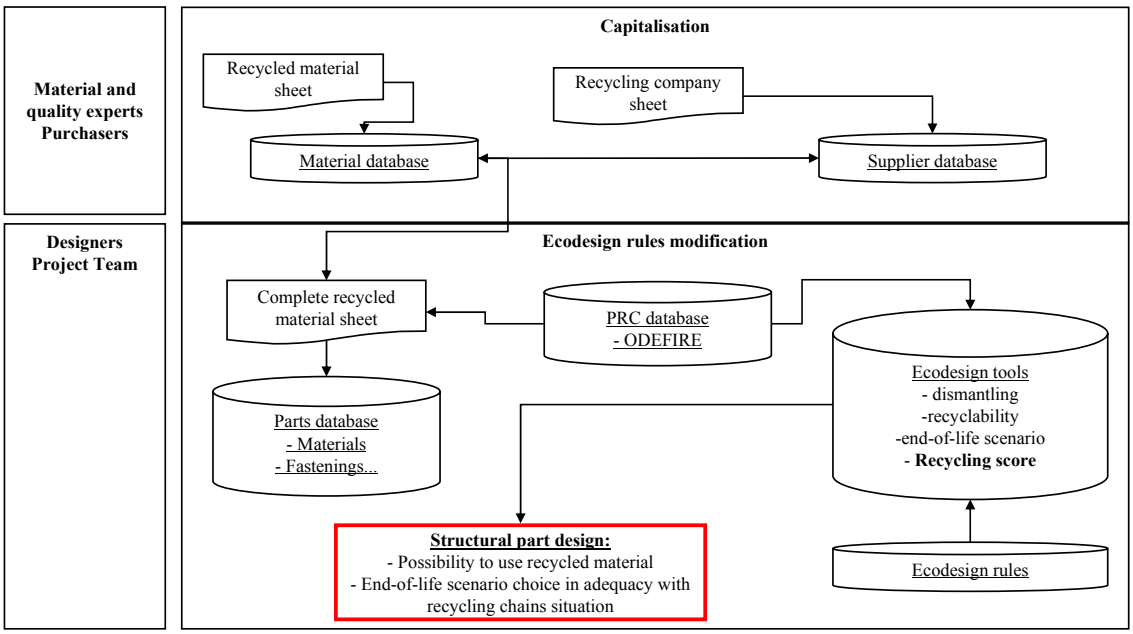

Figure 3: Knowledge accumulation and ecodesign rules changes to make the use of recycled plastics a common practice - Last stage of DAIMRE)

This mark is added to the existing eco-design rules (Figure 3) improving the reliability of the choice of the end-of-life scenario. For example, the choice of a recycling scenario by part dismantling with a recycling mark of 2 can suggest questions about the adequacy of the scenario, or about the possibility to conduct changes to develop such scenario or about the material choice as regards recycling. Consequently ecodesign rules are not sufficient without the integration of the use of recycled material. This conducts to consider at the same time the scenario (recyclability, dismantling), the PRC (mark), and the material characteristics (Figure 5).

4.2 Validation: GF-PP project at POAE's

4.2.1 Project description

POAE wants to standardize the use of recycled plastics in Technical Front End (TFE) design, part produced in GF-PP. This material is not currently recycled. To find solutions to this situation: POAE propose in a first time to produce recycled GF-PP from PP bumpers and thermosets glass fibres and in a second time they search to define the feasibility to develop recycling chains directly from TFE from existing PRC. We applied our approach to determine the possibility to use recycled PP-FV in design and to implement the recycling scenario through the assessment of GF-PP recycling mark.

The steps of the POAE project were [9]:

- Evaluation of the possibility to recycle GF-PP: POAE developed a new recycled GF-PP formulation with a recycling company. It was blended with GF-PP virgin material at the rate of 20% in order to facilitate its integration in design.
- Material characterisation and material sheet implementation: the compound characteristics and the balance between material properties and part specifications were evaluated.
- Measurement of the PRC's capabilities with ODEFIRE: We assessed the current and future technical and economic capabilities of the PP recycling chain. ODEFIRE gives the potential of the system to produce GF-PP, potential used to assess the recycling mark. It gives also the characteristics of the recycling companies capable to produce this material.
- Ecodesign rules: a dismantling scenario was chosen for TFE. We evaluated the possibility to dismantle, the GF-PP recycling mark and their adequacy.
- Integration of the recycled compound in a TFE design project: integration of a material sheet in the existing tools and design of production tools adapted to the recycled material. This stood for a great innovation for POAE. The material specifications were given to the recycling companies and the new material sheet including PRC's potential was given to purchasers, material and quality experts.

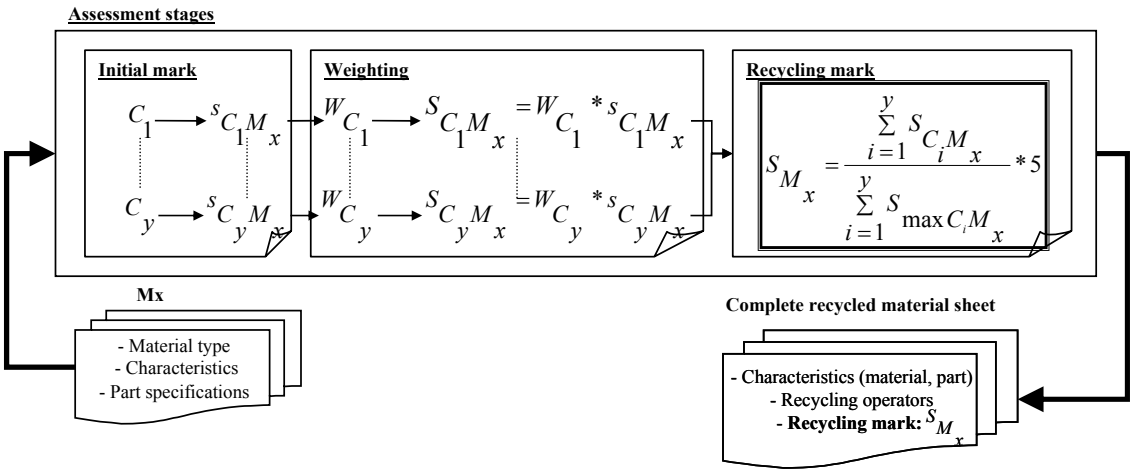

Figure 4: Recycling mark calculation for a material Mx and recycled material sheet implementation

4.2.2 Result: dismantling and recycling mark

The properties of the recycled GF-PP compound GF-PP corresponded to those of the virgin material. As expected, using 20% of recycled material did not induce property losses in comparison with virgin material. Moreover, we must note that this rate is also sufficient to reduce production costs for POAE. The recycled TFE properties in comparison with the project specifications were validated. ODEFIRE fed the capabilities of the PP recycling chains to produce recycled GF-PP. After discussion with experts about supplier criteria and their expectations, we assessed the recycling mark for GF-PP (Figure 5). We obtained 3,5. This mark signifies that there is no major risk to use such material in TFE design. This result is especially due to the strong development of existing PP recycling chains identified to produce this material. This sore was added to ecodesign tools. Then, we had to determine the best end-of-life scenario for TFE. We studied the possibility to develop a dismantling scenario in

order to provide high quality inputs to the recycling company and also to encourage the development of second life use for such parts. The analysis of dismantling with a method developed at POAE [25] revealed that it took a long time to dismantle such parts, time standing for a costly activity PRC's operators. Recycling GF-PP from TFE is possible but not from a dismantling scenario. A shredding scenario with plastics sorting can be suggested providing that the technologies to sort GF-PP should be developed and that the material grade obtained should be improved. For the moment, we can propose a recycling scenario from bumpers and thermosets glass fibres and a use of the recycled compound in TFE design in view of the recycling mark. We concluded that this recycled GF-PP could be integrated in design tools, proposed to manufacturers and used in TFE projects. One manufacturer accepted to use such a compound for its TFE. Design specifications and mould design were made specifically for this material. We must point out that the use of 20% authorized an easier integration in design than for a part made of 100% recycled. We can conclude that this integration was a success. Finally, the recycled GF-PP sheet obtained from material approval and including the recycling mark can be added to the material database and its use standardized for other TFE. POAE hopes to extend this approach to other materials.

Table 3: Recycling criteria, their values, weights and marks

Criteria	Definition	Weights	Value	Mark
V_{RM}	Recycled material volume available at recycling companies'	3	0	1
			<Project volume	2
			>Project volume	3
$N_{supplier}$	Number of suppliers supplying the material or capable to supply it	5	0	1
			[1-3]	2
			>3	3
P_{RM}	Recycled material price	3	0	1
			>=virgin material price	2
			<virgin material price or 15%<virgin material price	3
Ql_{RM}	Production of high-quality products for automotive markets	4	0	1
			High-quality	2
			Automotive high-quality	3
$Sol_{supplier}$	Supplier criteria to be part of the supplier panel	5	Profit margin<0	1
			Equilibrium	2
			Profit margin>0	3
$App_{supplier}$	Quality and environmental approval to be part of the supplier panel	3	0	1
			Quality	2
			All	3
$Loc_{supplier}$	Geographical situation of the supplier for logistical costs	2	Continent	1
			Country	2
			Region	3
Pot_{RM}	Potential of development of material recycling (volume, quality, price, suppliers) evaluated by ODEFIRE	5	0	1
			Average	2
			High	3

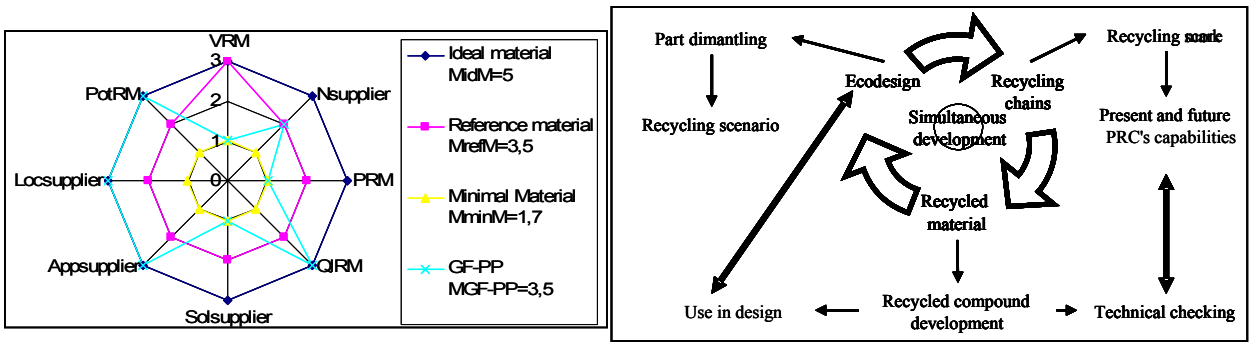

Figure 5: GF-PP mark and ecodesign rules modification at POAE's

This project allowed us to prove the reliability of our approach to develop the use of recycled plastics at POAE's but also the utility of ODEFIRE and the necessity to include the recycling mark to complete ecodesign rules (Figure 5). The material formulation in collaboration with recycling companies authorized also the development of existing structures insuring them an increasing knowledge of materials formulation and also time to find materials and create cooperation with other PRC's operators. This project confirmed also the necessity of finding and deploying this approach to give high-quality trade outlets to recycling companies in order to develop PRC.

5 CONCLUDING REMARKS

The development of a decision aid tool as ODEFIRE authorizes to fulfil the needs of all stakeholders involved in PRC's evolution. This requirement is a necessary condition to reach the real emergence of a professional and qualified PRC. We succeeded to obtain a PP recycling chain with a financial equilibrium and capable to produce a high quality recycled GF-PP meeting the automotive industry specifications only considering an increase of 20% in the virgin material price and a supply of more good quality PP waste to recycling companies. The DAIMRE approach led to the minimisation of risks to use recycled plastics in an automotive supplier design process. It allows to implement changes in ecodesign rules in order to obtain a complete adequacy between recycling capabilities and market specifications (recycled GF-PP for TFE). The creation of a recycling score breaks many barriers previously mentioned supplying a database with new information on PRC's capabilities. The results and approach presented underline that it is necessary to have a global view of the system and of the stakeholders' expectations in order to integrate PRC in the automotive supply chain. An integration of PRC in the automotive supply chain passes through the standardization of the practices developed by the recycling companies. Encouraging PRC's development by using recycled plastics in structural parts design appears to be the decisive factor in the implementation of a real ecodesign policy for plastic components.

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