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Light commercial vehicles designing with considering end-of-life vehicles recycling requirements

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Abstract. The issues of utilization of vehicles at the end of their life cycle are the most important from the ecological point of view. Foreign experience in the field of utilization of vehicles also makes it possible to talk about the economic efficiency of this industry, but in order to achieve high results it is necessary to take into account the requirements for recycling at the early stages of product design. This article analyzes the domestic recycling industry. The main barriers in the field of utilization of commercial vehicles have been identified. A methodology for designing light commercial vehicles (LCA) is proposed, which satisfies the utilization rates. A design algorithm is proposed to take into account the requirements of engineering analysis and economic feasibility, which ensures product orientation for recycling. Calculation of recycling indicators based on a complete set of information on vehicle components is given. Dismantling of vehicle components as a key process in the utilization structure is considered. A comparative evaluation of the efficiency of dismantling of plastic products of GAZ Group commercial vehicles was carried out.

1. Introduction

A growing fleet of cars and, as a result, the growing burden on the environment poses the task of minimizing the negative impact of vehicles on the environment. One of the key areas of increasing environmental friendliness is the task of recycling end-of-life vehicles. At the same time, the degree of reuse of materials and components used in the manufacture of cars is essential for improving the energy efficiency and resource saving of the economy.

Almost all main participants of the motor transport complex are interested in the recycling of cars. Automakers receive significant benefits through the use of cheaper secondary raw materials, trucking companies and car owners from the state provide cash subsidies. The Ministry of Industry and Trade, through recycling, promotes renewal of the fleet of vehicles. Renewal of the fleet is also beneficial for the Ministry of Transport: due to recycling of vehicles, the transport system safety is increasing and the environment is improving [1].

Foreign countries have tremendous experience in the field of vehicles utilization, as a result this sphere of activity brings quite impressive income, which allows the industry to develop itself without significant government intervention. So in the countries of the European Union, according to the

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European Association of Automobile Manufacturers, the profit from processing one car in the EU is about 340 euros [2].

2. Domestic experience in the field of utilization of vehicles

Unlike foreign countries, the domestic recycling industry is now in the initial stage of development. Along with the problems in the legal sphere and the lack of a unified system of utilization centers, there are difficulties in the utilization of vehicles, the design of which does not allow a qualitative and rapid implementation of the process of dismantling and subsequent processing of the product.

So the issue of utilization of light commercial vehicles of GAZ Group has a great importance in view of the fact that the company's products occupy about 70% of the total number of vehicles sold in this category on the domestic market. The adaptation of the design to recycling allows not only to meet environmental requirements in the domestic market, but also to contribute to the increase in the export potential of the product. For the most qualitative solution of the problem of motor transport utilization it is necessary, at the stage of designing new products, to put the possibility of maximal reuse and recycling of components and materials after the end of the operation phase of the car.

The solution of tasks related to the assessment of environmental friendliness and the development of methodologies for the design of vehicles, taking into account their subsequent disposal, involves various scientists and scientific organizations.

In the papers [3, 4] technological schemes for utilization of vehicle components and assemblies were considered, an analysis of foreign experience in the field of utilization was made, and the domestic regulatory framework was evaluated.

In the paper [5] the technique of an ecological estimation of cars in a full life cycle, considering stages of their manufacture, operation and recycling is presented.

In [6] the methodology of constructing advanced design of vehicles with their subsequent utilization is presented, which implies the use of a set of recommendations about the modular principles for the design of vehicle units and systems, the use of connections in the vehicle design that facilitate simplified disassembly of parts, and also sorting of materials, selection of structural materials in units and systems from the point of view of their compatibility in recycling.

Based on the results of the analysis, it may be concluded that the above-mentioned papers are expedient for the successful solution of the problem of utilization of vehicles.

However, when disposing of light commercial vehicles at the end of the life cycle, there are a number of features related to the lack of internal regulations defining the LCA design methodology, taking into account the suitability for recycling, the unpreparedness of the product composition database for calculation of recyclability indicators, the complexity of organizing work with suppliers parts and assemblies in terms of providing passports of materials and components, etc.

Depending on the choice of methodology for designing light commercial vehicles, taking into account the utilization, the output directly affects foreign markets, in particular the EU market, as well as the markets of the Russian Federation and the countries of the Customs Union, which tend to tighten environmental standards. A detailed study of the requirements of the UN Regulations and the EU Directives (UN Regulations 133, Directives 2000/53 / EC and 2005/64 / EC, ISO 22628: 2002, etc.) has shown that to bring the design of new and already produced vehicles into compliance with the requirements of recycling it is necessary to create a methodology for the design and development of light commercial vehicles that meet the utilization rates.

3. Development of a methodology for the design and development of light commercial vehicles that meet utilization rates.

At the first stages of the development of this methodology, a number of approaches were identified that should be applied to the automaker:

- Development and implementation of a set of management standards for disposal targets;
- Creation of a specialized teamwork environment for representatives of various areas of product design and production;

– Development of a design focused on the possibility of processing for the purpose of reuse;
– Early involvement of suppliers in work to ensure suitability for disposal;
– Refusal to use hazardous materials, or non-exceeding of limit values (lead, cadmium, mercury, hexavalent chromium);
– Use of materials suitable for recycling and reuse;
– Identification of components from polymers and elastomers;
– Development and provision of accessibility of Catalogs of disassembly of vehicles for recycling companies;
– Guarantee the possibility of re-use of more than 85% of the mass of the car, laid down already at the design stage.

The algorithm for designing light commercial vehicles taking into account the requirements for disposal at the end of the life cycle, combining these approaches is as follows.

At the initial design stage, the functional purpose of the product is analyzed and in parallel, according to regulatory documents, the design requirements for the product regarding the possibility of its reuse, recycling and recovery are determined. Based on this analysis, the structure of the product and the choice of its material are formed. When the product characteristics are consistent with the requirements of engineering analysis, an assessment of the suitability of the product material for its recycling is made. In the case of a negative evaluation of suitability, the possibility of changing the type of the material of the product and the ease of dismantling the product are considered. After satisfying the requirements of engineering analysis, suitability for recycling and ease of dismantling, the costs and benefits of processing the product are considered, taking into account the production budget. If the results of calculations are consistent with the specified requirements, an analysis of costs and profits in the manufacture and processing of the product is made and the start of production begins. If the results of the calculation are not in accordance with the requirements, the design of the product is changed, beginning with the first stage of this algorithm.

In the process of designing a new car, the features in terms of recycling are built into the overall work flow, presented in Figure 1.

At the product planning stage, legislative requirements are defined in the markets for the intended sale of cars. A database is formed on the composition of the product with the possibility of calculating the utilization rates. At the product development stage, the recycling requirements are included in the technical requirements for the component supplier. The design takes into account the limitations and recommendations on the suitability of vehicles for disposal, a vehicle is selected for the calculation of indicators. At the stage of preparation of production from suppliers, they receive confirmation of the compliance with the requirements for disposal in the form of certified material passports of components. In preparing the production, also, the requirements for the suitability for disposal in relation to the production process are taken into account. At all stages, the calculation of the utilization indicators and the necessary adjustment of the design and technology are monitored (in case of non-conformance detection).

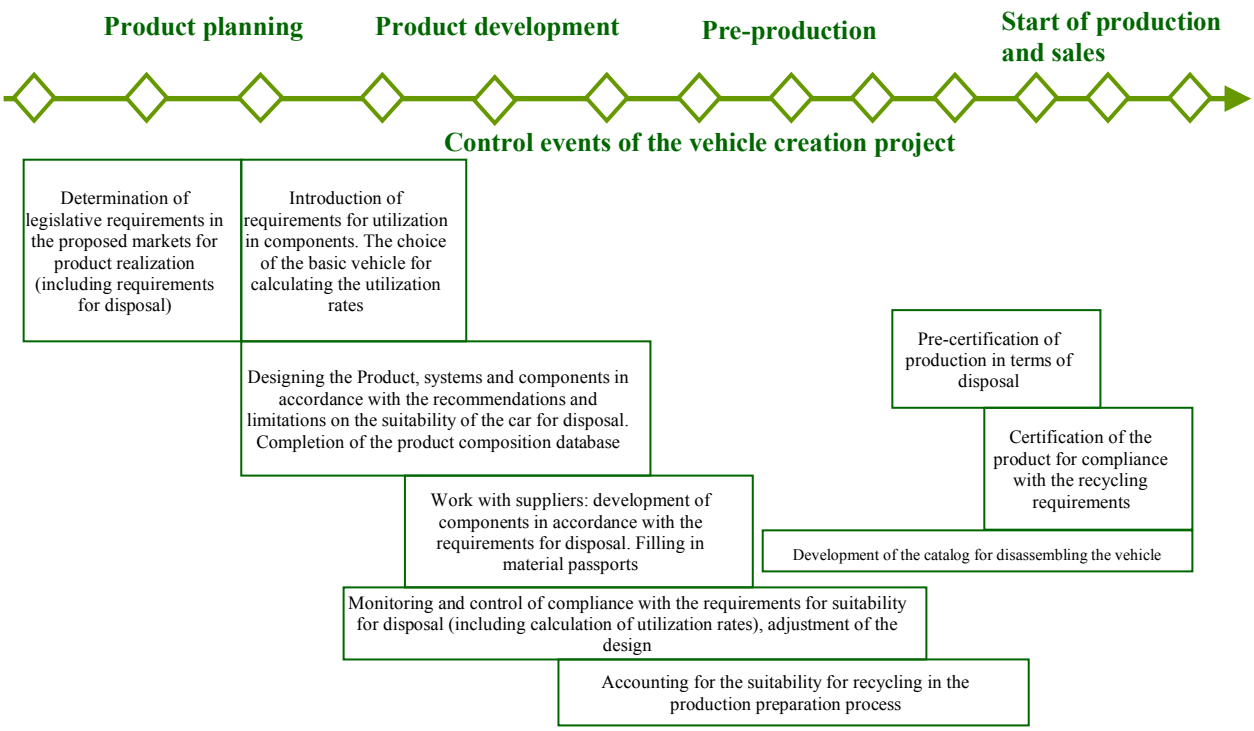

Figure 1. The work flow in order to meet the requirements for suitability for recycling when creating a product.

From the point of view of the product, the following features can be distinguished while ensuring its suitability for disposal:

Product concept:

– maximum coverage of the functional characteristics requested by the market by creating a product line with the minimum number of options required;

– exact fulfillment of customer expectations without understated or excessive product characteristics;

– Optimization of the design of the vehicle with respect to the identity of the main characteristics of components (equal resource, identical quality level);

– minimization of the material consumption and energy consumption of the product throughout the life cycle;

– design with easy disassembly. Ensuring the resistance of compounds to the effects of time (corrosion, aging, change in properties), i.e. whether it will be possible to disassemble the car in 10 ... 15 years as easily as at the time of assembly;

– minimization of the nomenclature of components from various materials, i.e. it is necessary to strive to use the same components and materials.

Use of environmentally friendly materials in the design:

– minimization of the use of hazardous materials (lead, mercury, cadmium, hexavalent chromium);

– preference for the selection of materials having the lowest energy input in the production;

– use of materials most suitable for reuse;

– reuse of materials obtained as a result of disposal;

Reducing the mass-dimensional characteristics of the product components:

– reducing the mass and volume of components contributes to reducing logistics costs in production and power consumption during the operation of the car;

Optimization of production technology:

– the use of technological processes with a minimum energy intensity and the lowest emissions of harmful substances;

– minimization of the number of technological operations;
– use of materials that do not require additional surface treatment of parts;
– minimization of waste generation;
– recycling of waste in the same process;
– the use of secondary materials in the production of cars.

Use of the product at the end of its life cycle:
– at the design stage, to consider the possibility to reuse components after appropriate repair;
– the design should allow easy disassembly and separation of materials;
– use a modular design that simplifies disassembly;
– Materials must be labeled (especially polymers and elastomers) to speed up their sorting;
– The more materials are recyclable - the less waste will be left for burial;
– parts and assemblies, which containing hazardous materials must be easily removed to avoid further contamination of the environment (especially when burning the waste).

Since the indicators of suitability for utilization and recovery are determined by the calculation of the masses of materials of vehicle components identified in the technical documentation of the automaker with subsequent monitoring of actual deviations in production - the issue of mass management is one of the key values in the management of disposal targets. The procedure for controlling the target vehicle mass is shown in Table 1

Table 1. Procedure for controlling the target vehicle mass

№	Action	Stage of product creation
1	Analyze trends in the change in the mass characteristics of cars and their components in future periods. Carry out an analysis of previous models of own production. Conduct an analysis of the mass values of products of competitors and their components in the work of benchmarking.	Planning
2	Set the target masses for the basic modifications of the car in the product family	Planning
3	To present the engineering composition of basic modifications to large systems - the first level of decomposition (body, chassis, electronics, ...). Carry out a breakdown of the target mass of the product into systems.	End of planning phase
4	Carry out the decomposition of systems into subsystems (wheels, gearbox, ...) - the second level of decomposition. Carry out a breakdown of the target mass into subsystems.	Start of development
5	Decompose the subsystems into components - the third level of decomposition. Carry out a breakdown of the target mass into components.	Development
6	Development of components design in the framework of non-exceeding of the target mass. Correction of mass distribution in justified cases.	Development
7	Confirmation of achievement of target values in production. Carrying out structural changes in justified cases.	Pre-production

Calculation of recycling indicators is carried out on the basis of a complete set of information on the composition and masses of each component of the vehicle, up to fasteners, seals, fillers, solders, etc. The relationship between the stages of recycling the vehicles and calculating the suitability for utilization is shown in Figure 2.

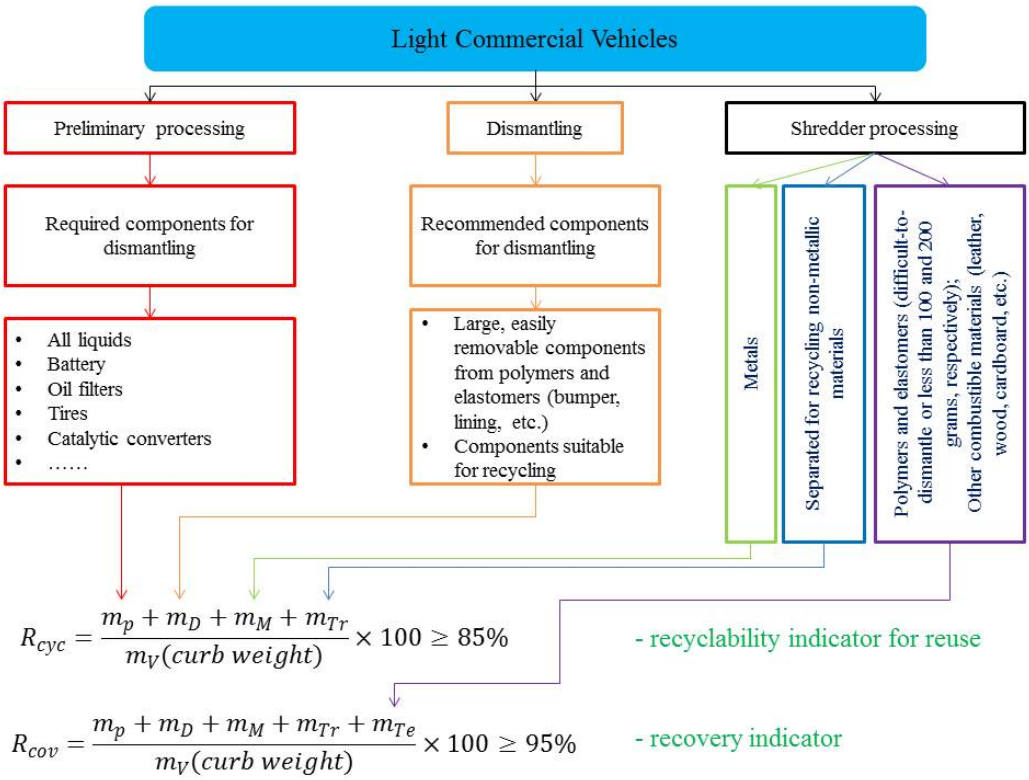

Figure 2. The relationship between the stages of recycling of the vehicle with the calculation of the suitability for utilization

Another key point in the suitability of cars for utilization is the provision of an efficient process of disassembling the car at the end of the life cycle [7,8]. This criterion is directly related to the economic efficiency of car recycling. The time for disassembling the car is determined by the features of its design, the elements of fastening the units and parts, the availability of instructions for disassembling, etc. To date, many foreign automakers are paying special attention to the time costs associated with disassembling the car, as the disassembly time increases, the total cost of car recycling also increases.

In view of the foregoing, in order to minimize the time and financial costs for the disposal of light commercial vehicles, special solutions and limitations are being put at the design stage, simplifying disassembly. Using the CAD system and a specialized process simulation system, an imitation of the component is simulated with the calculation of the trajectory and the time of operations. An example of modeling the dismantling of plastic parts of the GAZelle Next cladding is shown in Figure 3.

To evaluate the effectiveness of the dismantling of GAZelle Next plastic details, which was designed to take into account the dismantling requirements for disposal, and GAZel Business (GAZ 3302), which did not have the requirements for dismantling the components, comparative tests were carried out. The essence of the tests was to estimate the number of plastic components and the time taken to dismantle them. Despite the fact that the number of plastic parts in the GAZelle Next car, compared to GAZelle Business, is more by 15%, the time spent on dismantling this type of products is less by 25%. Based on the results of this experiment, it can be concluded that this approach allows to minimize the time and material costs for ensuring the dismantling of components, as well as to increase the number of dismantled non-metallic parts, which increases the car's availability for recycling.

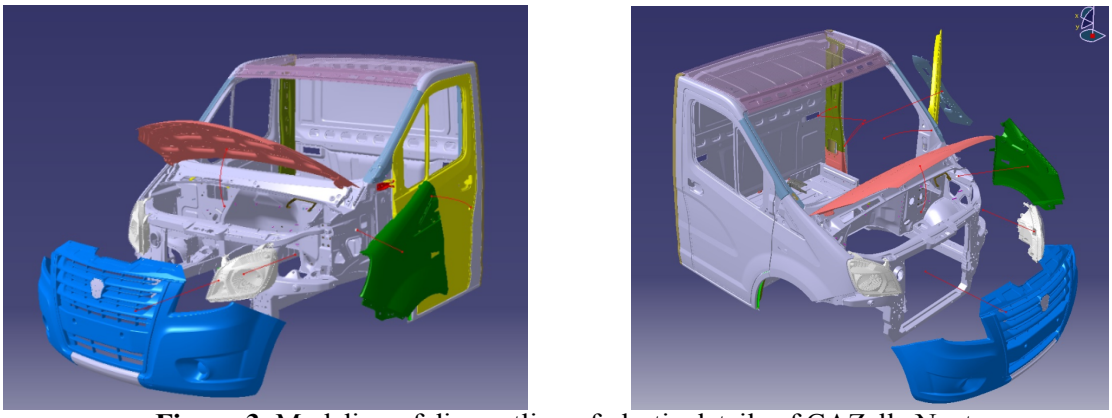

Figure 3. Modeling of dismantling of plastic details of GAZelle Next

The result of the above works is the catalogs for the disassembling of light commercial vehicles of the GAZ Group, which meet the requirements of the EU regulations on the suitability of vehicles for disposal.

4. Conclusions

Thus, to ensure the leading position of the LCA GAZ on the domestic market and the growth of sales in foreign markets, a significant increase in the environmental safety of products was achieved, including by ensuring the suitability for disposal at the end of the life cycle. The results of this work allowed to implement the project to develop new and bring already produced light commercial vehicles GAZ in line with the European requirements for the suitability for disposal at the end of the life cycle.

It is worth noting that, with the direct application of the above-described methodology for designing light commercial vehicles taking into account disposal at the end of the life cycle, certificates of compliance with Directive 2009/1 / EC and 2005/64 / EC were obtained for production and products respectively, which is one of the conditions for access to export markets.

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