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Development Methodology of Light Commercial Vehicles Designing with Considering End-of-Life Vehicles Recycling Requirements

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Abstract. The experience of European recycling industry shows that modern recovery technologies provide economically effective recycling process of vehicles. However, automotive recycling is still not a financially independent industry. To obtain high level of efficiency requirements for recycling must be taken into account on earlier stages of vehicle design. This paper is dedicated to light commercial vehicles (LCV) design process with taking into account requirements for recycling, recovery and reuse. An analysis of Russian and foreign legislation in the field of automotive recycling is presented. As one of the most important result of the work a methodology of LCV design with taking into account requirements for recycling was created. The methodology includes engineering and economical analysis that provides possibility to achieve the highest results for each specific new type of vehicle as well as to justify the use of non-metallic components. A calculation of recycling rates is presented as an example. In order to reduce labor intensity and speed up the dismantling process a simulation of dismantling was performed with an analysis of trajectories and spent time for each component considered for dismantling.

1. Introduction

Recycling, recovery and disposal are one of the most important ecological issues of automotive industry. Currently only Japan, USA, China, Korea and countries of European Union have well organized end-of-life vehicle (ELV) recycling systems that are functioning under legislative control [1,2].

Development of the Technical Regulation of the Customs Union on vehicle recycling was initiated after the entry into force of the European Directives 2000/53/EU and 2005/64/EU which introduced requirements on ELV treatment. The Regulation has passed the stage of social discussion and, as EU Directives mentioned above, contains requirements for automotive producers on mass characteristics of vehicles (85% of vehicle mass should be suitable for recycling and 10% – for energy recovery), on company internal standards, which must take into account recycling requirements, development of information on dismantling (mass, placement and processing method of components at the end-of-life stage) and ect [3–6].



The UN Regulation No. 133 "Uniform Provisions Concerning the Approval of Motor Vehicles Regarding the Possibility of Their Reuse, Utilization and Recovery", that was released in June 2014 under the Geneva Agreement of 1958, became a subject to further distribution on the territory of the Russian Federation and other Customs Union States [7].

The indicated tendencies set the task for Russian automakers to bring their products into compliance with new requirements and develop mechanisms for their implementation during the design process. At the same time, the utilization of light commercial vehicles (LCV) at the end of their life cycle has a number of features related to the lack of internal regulatory documents defining the LCV design methodology that would take into account the suitability for recycling. In particular, difficulties can be observed in unpracticalness of the product composition database in terms of calculation of recyclability rates, in complexity of collaboration with suppliers of parts, units and assemblies in terms of obtaining passports of materials and components, etc.

In view of the foregoing, it becomes evident that there is a need to develop an integrated methodology of LCV design that ensures their suitability for recycling at the end of life cycle.

2. Methodology of LCV design with taking into account requirements on recycling

Most modern vehicle manufacturers use an integrated, standardized design process that covers all areas, from understanding the needs of markets and ending with the launching of the finished product to the market. This process is divided into key phases with clearly defined and interrelated goals and key points. In the worldwide practice such approach is known as "Quality Gates System". It implies implementation of a product creation project by a single project team and each major direction of work is seen as a second-level process and is characterized by documented interrelationships with other related processes [8].

Meet of the requirements on recycling is one of the particular tasks in a common product creation process, and therefore it can be presented as a second-level process "Management of recycling targets" integrated into overall design system. At the same time, a systematic approach to the complex implementation of the requirements for the suitability of vehicles for reuse and recycling is needed (figure 1).

Thus, development of a comprehensive methodology of LCV design, ensuring their suitability for recycling at the end of the life cycle, involves the solution of the following tasks [9–12]:

- Development of a methodic of management of recycling targets
- Adaptation of the methodic of recyclability rates calculation in respect to particular features of LCV structure and production
- Development of an automated system for management of recyclability rates of LCV based on existing LCV Composition Management Data Base
- Development of a methodic of simulation of LCV dismantling at the design stage
- The novelty and unusual nature of the process consists in necessity for the Russian automakers to take special measures for implementation of the methodology directly in product projects in addition to preparing standards and conducting training.

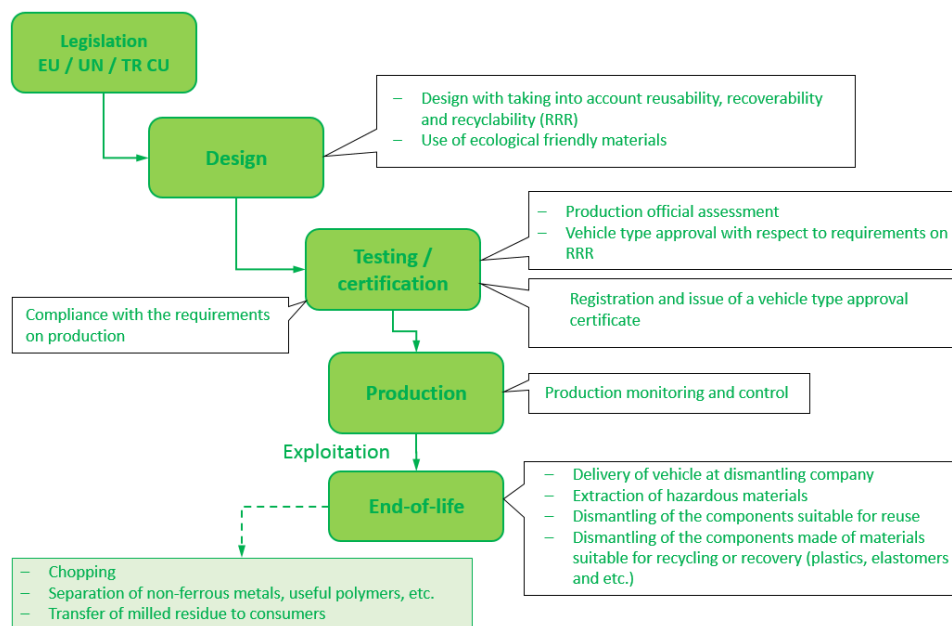


Figure 1. Recycling in terms of vehicle life cycle.

Main steps of the methodology creation implied development of several approaches that are needed to be implemented by automakers in order to ensure implementation of the legislative requirements on ELV recycling [13,14]:

- Development and introduction of a set of standards on management of recyclability targets
- Creation of a specialized teamwork environment for representatives of different areas of product design and production
- Development of a design focused on possibility of processing for the purpose of reuse
- Early involvement of suppliers into works on ensuring recyclability
- Refusal of hazardous materials (lead, cadmium, mercury, hexavalent chromium), or not exceeding of their limit values
- Use of materials suitable for reuse and recycling
- Marking of components made of polymers and elastomers
- Development of dismantling catalogues. Providing accessibility to catalogues for ELV dismantling companies
- Providing possibility of reuse of more than 85% of the mass of vehicles, laid down at the design stage

In accordance with the developed methodology (figure 2) the product planning stage implies analysis of current legislation on ELV treatment on supposed markets as well as creation of the product composition data base which provides possibility of calculation of recyclability rates. At the stage of product development requirements on recycling must be included into technical requirements for suppliers. Restrictions and recommendations related to further recycling of the vehicle must also be taken into account during product design. At the same stage a basic vehicle modification must be chosen for calculation of recyclability rates.

At the stage of production preparation the material passports of components should be obtained from suppliers as confirmation of implementation of requirements on recyclability. Requirements on recyclability should also be taken into account at the same stage.

Monitoring of recyclability rates and correction of design if needed (if any nonconformity is observed) are performed during the whole stage of the product development.

By the moment of start of production a preliminary assessment of automaker should be performed and a Certificate of Compliance (CoCom) shall be emitted as the result.

The vehicle type approval certificate of compliance on recycling requirements shall be obtained by automaker before the start of sales.

A systematic control of production in terms of implementation of requirements on recycling as well as assessment of supplied components is continuously performed during the production.

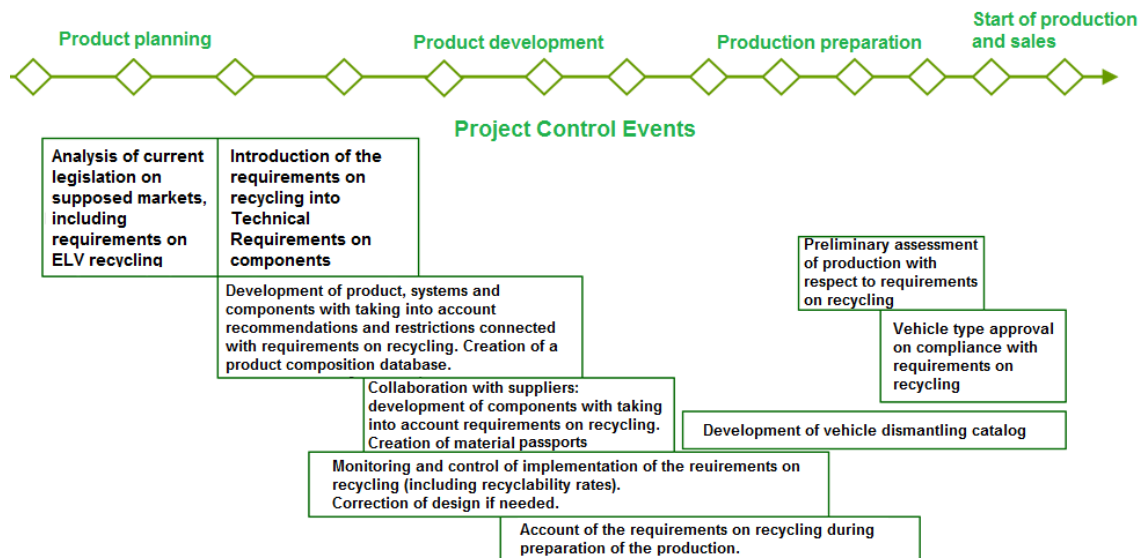
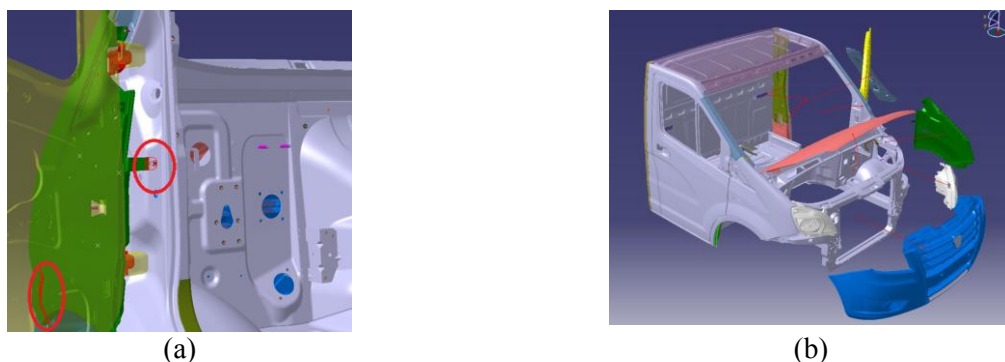


Figure 2. The general scheme of implementation of requirements on recycling in a product project.

3. Dismantling as a key part of recycling process

Dismantling is one of the most responsible stages of ELV recycling process in terms of reaching the recyclability rates laid down into vehicle design. As example, choosing of plastic components and taking them into account as suitable for reuse during the calculation of recyclability rates don't have sense if in real life they are not separated from vehicle and not processed in proper way [15].

In order to provide convenient disassembly of vehicle at the end-of-life stage a simulation of dismantling process was performed at early stages of structure design. A 3D CAD-system and a specialized system for technological processes simulation were used in order to perform a virtual trial of disassembly process. This helped to analyze "conflict" cases for mated components (figure 3(a)) and to consider them during the calculation of optimal dismantling trajectories (figure 3(b)) and time per operation.



(a) dismantling of fender as an example of imaging of penetration of mated components, (b) final trajectories of components motion during the dismantling process.

Figure 3. Simulation of dismantling of front bumper, fender and other large nonmetal parts of a LCV cabin.

The developed methodic provided a possibility to minimize time and material costs of assuring the suitability of components for dismantling as well as to increase number of nonmetal parts recommended for dismantling at the end-of-life stage. Finally all this measures helped to improve recyclability rates.

4. Calculation of recyclability rates

The recyclability and recoverability rates are determined by calculation of materials masses of vehicle components, which are indicated in automaker's technical documentation keeping in mind subsequent monitoring of actual deviations during the production. In regard to this, control of masses of materials is one the most important issue in terms of management of recycling targets.

Management of recyclability rates is most expedient to perform with the use of electronic databases contained in automaker's PDM-systems which allow to manage the data on recycling in parallel with the tracking of vehicle composition.

In order to simplify the process of tracking of vehicle composition it was expedient to create a digital material tickets for each material or component. Such tickets contain information on material composition, component marking, mass characteristics, presence / absence of hazardous materials, dismantling status (obligate / recommended / other), information on coating, status of design documentation and etc. Thus, digital material tickets allow:

- to manage the recyclability rates (masses, dismantling status)
- to control hazardous materials
- to track the marking of components made of polymers and elastomers

Calculation of recyclability rates was performed for basic vehicle modification with the use of complete set of information on vehicle (set of digital material tickets). The method of calculation is contained in ISO 22628:2002 – "Road vehicles. Recyclability and recoverability. Calculation method" [16]. "Basic vehicle modification" means a vehicle of the same model, modification of which contain minimum percentage of mass of metal components, maximum percentage of nonmetal components and implies other characteristics that make it difficult to process and reuse components of such a vehicle. Tables 1 and 2 are presented as an example of reporting forms of recyclability rates calculation for a LCV performed with the use of product composition database.

Table 1. Categories of materials that are taken into account in calculation.

Code	Material category
01	Ferrous metals
02	Nonferrous metals
03	Plastics
04	Rubbers (elastomers)
05	Glass
06	Liquids
07	Natural organic materials (wood, leather, cotton, cardboard and ect.)
08	Other materials as well as materials that cannot be divided into categories

Table 2. Composition of basic vehicle modification with respect to material categories.

Estimated vehicle weight, kg	Material masses with respect to categories, kg								Mass of lead per vehicle, g
M	01	02	03	04	05	06	07	08	
2119,716	1648,705	61,694	135,300	80,747	47,308	86,343	34,728	24,892	21,275
%	77,78	2,91	6,38	3,81	2,23	4,07	1,64	1,17	0,001

The column "Mass of lead..." contains information on mass of lead presented in solders that are used in components, electronic connections and equipment which contain lead in a glass or in a

ceramic matrix, with the exception of the glass of electric lamps and spark plugs, determined by an automated calculation of the composition of the vehicle.

Masses of components dismantling of which is obligate (MP = 160,189 kg) and recommended (MD = 75,144 kg) have been taken into account during the calculation process.

Table 3 contains data on final mass indicators. The results of the calculation in Table 4 showed that more than 90% of the mass of the developed LCV is suitable for reuse and should not be disposed. In view of the possibility of energy recovery, more than 98% of the vehicle mass is suitable for secondary use. It should also be noted that the mass distribution by categories of materials in a modern LCV is similar to that of conventional cars (Figure 4) [17]. To a large extent, this is due to the tendency to increase the level of comfort of modern LCV through a wider use of such nonmetal components as facing boards, auxiliary electronics and etc.

Table 3. Masses of lead and other materials obtained after excluding of components obligate and recommended for dismantling.

Vehicle weight after dismantling MP and MD, kg	01	Material masses with respect to categories, kg								Mass of lead, g
M0	M1	M2	M3	M4	M5	M6	M7	M8		
1884,383	1640,278	48,924	106,927	23,737	4,923	-	34,728	24,867	21,275	

Table 4. Recyclability rates of a basic modification of LCV.

Indicator	Equation	Result, %
Reusability	$R_{cyc} = 100 \cdot (MP + MD + M1 + M2) / M$	90,79
Recoverability	$R_{cov} = 100 \cdot (MP + MD + M1 + M2 + M3 + M4 + M7) / M$	98,59
Not recyclable (residue)	$R_{non} = 100 \cdot (M5 + M6 + M8) / M$	1,41

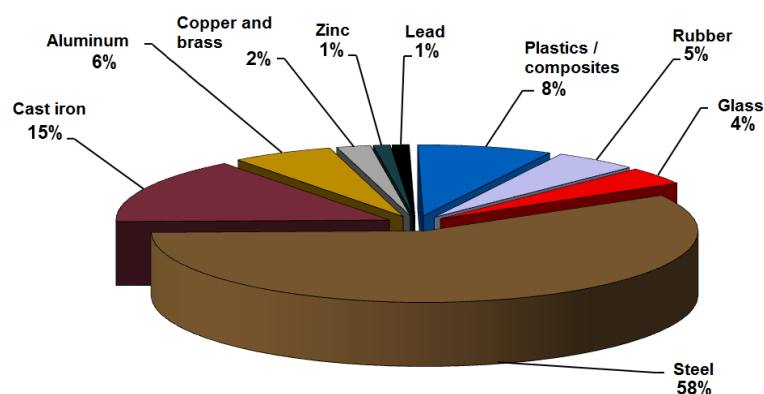


Figure 4. Material composition of a conventional car.

5. Conclusions

The main results of work are the following:

- A specialized approach of the management of recycling targets based on project organization of work was proposed and tested
- A normative and methodological base was created
- Specialized training programs were developed
- A systematic approach of LCV design that provides suitability for recycling was proposed
- Meet of the requirements on recycling was investigated as one of the particular task in a common product creation process. It was integrated into overall design system as a second-level process "Management of recycling targets"

- The order of interaction between different areas of product development (design, testing, interaction with suppliers, production engineering, quality, etc.) was introduced
- Specialized methods and instruments for vehicle design with taking into account further recyclability were developed
- Part of the product composition database that is used for information management and calculation of recyclability rates was finalized and adapted
- Based on the results of studies, simulation and experimental disassembly, a methodology for creation of LCV dismantling catalogs was developed. The methodology implies possibility of creation of catalogs at early stages of vehicle design. Catalogs created with the help of the developed methodology satisfy requirements of EU Directives
- A calculation of recyclability rates for a basic modification of LCV was performed

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