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The Role of Reverse Logistics in the Transition to a Circular Economy: Case Study of Automotive Spare Parts Logistics

The article describes the ways of industrial development in the era of transition from a linear model of the economy to a circular model, as well as new trends in the development of logistics. It shows the interconnection of processes in production systems, logistics and services, their role in ensuring sustainable green growth. It is shown that by closing the loop of product lifecycles, reverse logistics plays an important role to transitioning to a circular economy. The article presents an example of planning the supply of spare parts when organizing services in foreign markets. Planning is based on multidimensional analysis of failure and modeling data. For this purpose, an information system was developed. The found failure probabilities of units and parts were used to build a model of the reverse logistic chain, within which the parameters of the formation of a reverse flow, differentiated for various operating conditions and vehicle subsystems, were introduced for the first time.

Keywords: Circular economy, Reverse logistics, System of branded automotive service, Spare parts logistics, Decision support system.

1. INTRODUCTION

Globalization processes have led to the realization of the need to find ways of transition to a new model of the economy. Depletion of resources, climate change, negative impact on the environment – these are the factors that raise the question of responsibility to future generations for the preservation of life on the Earth. These are challenges of a planetary scale. In today's world, the basic model for the production of goods is linear: natural resources are extracted and turned into products that are used for a limited time (Fig.1). While some of these products are recycled, most eventually end up in the world's landfills. This model is becoming increasingly unsustainable and expensive for businesses.

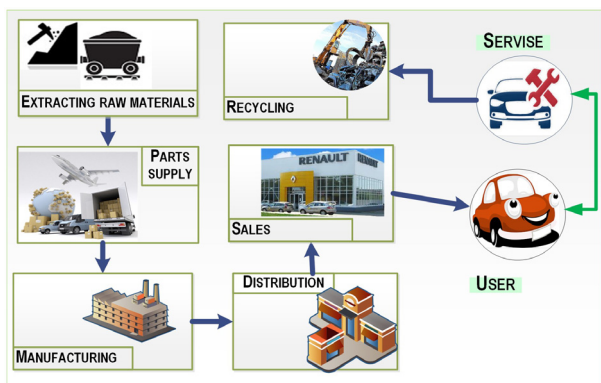


Figure 1. Linear economy model

Demand for goods and services coupled with increasing resource scarcity and price volatility is causing companies to move from a traditional “take-make-dispose” model to a more circular strategy [1], which has a restorative and closed character [2] and is based on minimizing the consumption of primary raw materials and reducing waste disposal. Beyond the cost, there is increasing awareness of the impact of the linear model on the well-being of the planet, and a growing sense of urgency as we see the ultimate ramifications on society and the environment. All this fully correlates with such a key direction of the Fourth Industrial Revolution as the formation of eco-friendly technical and technological systems. According to the research of the international company Persistence Market Research (2015) [3], their introduction into the automotive industry, will create an opportunity to reduce the consumption of raw materials by 98%; to save 83% of energy; decrease the cost of finished products up to 40% and carbon dioxide emissions up to 87%.

Closed-loop supply chains form the basis of the circular economy, for which it is necessary to apply fundamentally new logistics approaches (Fig. 2). One of such approaches is called reverse logistics and implies the movement of material flow from the consumption point to the original place of production [4]. Circular economy is currently a popular concept promoted by the EU, by several national governments, including China, Japan, UK, France, Canada, The Netherlands, Sweden and Finland, and by many businesses around the world. Therefore, European Commission adopted an ambitious Circular Economy Package, which includes measures that will help stimulate Europe's transition towards a circular economy, boost global competitiveness, foster sustainable economic growth and generate new jobs [5].

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This document contains the EU circular economy action plan that establishes a concrete and ambitious programme of action, with measures covering the whole cycle: from production and consumption to waste management and the market for secondary raw materials and a revised legislative proposal on waste.

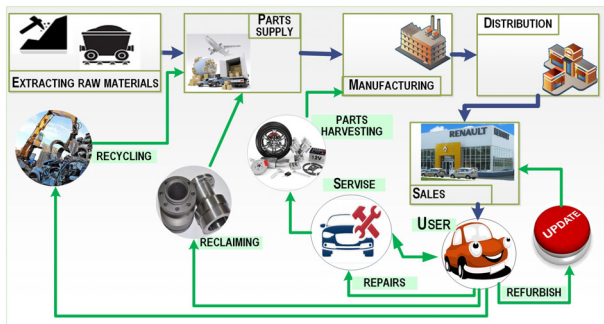


Figure 2. Circular economy

The EU is confident that the proposed actions will contribute to “closing the loop” of product lifecycles through greater recycling and re-use, and bring benefits for both the environment and the economy. According to a report by the World Economic Forum, a shift away from a Linear Economy to a Circular Economy by 2025 could generate an estimated \$1 trillion annually in economic value globally, create more than 100,000 new jobs, and prevent 100 million tons of waste within the next five years.

2. LOGISTICS IN A CIRCULAR ECONOMY

2.1 Logistics features in a circular economy

It is easy to see how reverse logistics fits in a Circular Economy. Bringing products back for their next use is a central focus of the reverse logistics profession. However, the reverse logistics industry will need to adapt a completely new mind-set to move to a circular economy. With approximately 97 percent of business leaders listing logistics as important to transitioning to a circular economy, collaborating with intelligent logistic providers will be crucial for companies to implement cost-effective circular strategies.

Businesses also need to examine their own supply chain and operations to identify areas where they can make improvement. Each product in a company’s supply chain must be analysed based on its unique characteristics from raw material to end-of-life. Then circular planning must be used to determine whether reclaimed products and resources should be transported back to a central hub facility or dealt with on a local level. Companies will need to commit to examine the inner workings of their manufacturing process and supply chains to identify areas for improvement. There is a number of barriers to widespread adoption: from the geographic dispersion of supply chains to the complexity of materials and deconstructing products. Digital and technology innovations are providing companies with the opportunity to overcome such barriers [6]. Machine-to-machine and data analytics enable companies to match the supply and demand for underused assets and products. And, 3D printing creates

opportunities for manufacturing inputs that are biodegradable [7].

For a long time, reverse logistics has been seen only as logistics going in the “wrong direction”. But that should no longer be the case. In the last 15 years, more than 260 Extended Producer Responsibility policies, which drive return flows, have been adopted worldwide. In France, one out of every five tons of material flowing through the economy is waste (and therefore, return flow), and the importance of reverse logistics continues to grow as the transition towards a circular economy accelerates. Before setting up reverse flows, companies need to make sure products can be reused, remanufactured, repair or recycled. There is no point getting a product back if its value cannot be recovered.

In a circular economy where materials are kept in circulation at all time, reverse logistics could represent a great opportunity the logistics sector cannot afford to miss.

2.2 Circular economy's problems and examples of solutions

To reach sufficient scale and build effective and efficient reverse logistics, companies need to consolidate their return flows by collaborating along the incumbent value chain, and adjacent or cascaded activities. Return flows are usually easier to consolidate across companies than forward flows because they are not subject to the same timing and confidentiality constraints. Some service providers are offering to aggregate return flows within industry sectors. For example, CoremanNet, a subsidiary of Bosch Group, has set up a dedicated logistics network and associated information system to manage the return flows in the automotive remanufacturing industry.

Because users of end-of-life or end-of-use products trigger reverse flows, they need to be included in the reverse logistics. To get their products back, companies can incentivize their users to return them. Caterpillar links used engine cores to a deposit and a discount system to maximize the capture of used components into their remanufacturing operations. New technologies can also help firms manage return flows that are less predictable and more variable than forward ones. For example, connected devices can track the location and condition of assets and resources. Businesses can know where their assets and materials are, even after they exit the supply chain, and quantify recovery value on a product-specific level. Komatsu, the manufacturer of construction and mining equipment, has fitted all standard equipment with sensors that send data to a central platform. The platform is able to compile and analyses data on equipment location and condition, allowing Komatsu to quantify the cost and benefits of various reverse logistics options, including reusing, remanufacturing or refurbishing. It also allows the company to better plan maintenance operations.

2.3 Reversible logistics in the automotive industry

There are many different opportunities to help sectors and companies evolve their business into a more “circular”

way of operating. While some industries may eventually face with significant disruption externally, there are also ways in which a business can evolve more gradually towards this way of operation. Development of automotive industry and the growing competition in global markets lead to the emergence of new trends, such as expanding the network of assembly factories in different countries, automotive vehicles' line-up renewal, including the emergence of more environmentally friendly and energy-efficient models. In such conditions, the need for more reliable and efficient logistic models associated with the delivery of components to the conveyor, as well as spare parts to service centres, inevitably increases. In addition, over the past few decades, the sustainability of supply chains and logistics networks has received considerable attention in connection with the development of the "green economy" concept.

Suppliers in the automotive industry for manufacturers such as Ford (Europe), have successfully developed reverse logistic approach over the past years by designing returnable, robust, re-usable storage trays for the delivery of components, rather than create endless packaging waste [8]. Once components have been delivered to site, the return journey of the delivery vehicle is filled with the packaging from a previous drop off. In a staged approach, recycling solutions may first be adopted, and with these in place, the supply chain is ready to progress to reuse options, as in the example at Ford above.

In the case of automotive spare parts delivery, the decision on spare parts repair or remanufacturing have to be based on the failures statistics. If the spare part cannot be repaired in the branded service autocentre, it has to be delivered to the manufacturer for disassembly, replacement of components where necessary and assembly of a product to bring it back into as-good-as-new condition. In this case, one of the most urgent tasks is to build spare parts' reverse supply chains with account of many factors influencing on delivery efficiency, and, accordingly, overall manufacturing operation. In most studies [9-11], the efficiency of supply chains is assessed mainly in terms of minimizing transportation costs and delivery time. However, nowadays, the notion of efficiency should be considered from all three dimensions, such as economic, environmental and social [12]. It is possible to determine such ways to increase the environmentally friendliness of spare parts delivery, as the use of "green" vehicles, the shift to intermodal and terminal transportations, the development of routes taking into account the environmental situation along the route and minimizing empty runs.

2.4 Modern logistics systems for the supply of automotive spare parts

Modern trends in the automotive industry show that to ensure the competitiveness of the business it is necessary to have a developed logistic system. Such a system is the basis for interaction between production and service systems in the implementation of the principles of the circular economics and green technologies. If it concerns the organization of effective delivery of spare parts, firstly such tasks, as the choice of delivery mode,

transportation mode, as well as the best route selection should be considered and solved. Since transportation of automotive spare parts is a very complex process, decisions are often made under conditions of incomplete information.

In order to identify all the significant factors, the complete, relevant and adequate information, as well as the application of tools and methods of its processing and analysis is needed. Multi-criteria analysis methods, online analytical processing (OLAP) technologies, simulation, as well as the elements of situational management have to be used to make the final managerial decision. In addition, since any error in supply chain management can lead to financial, time and other losses, methods of risk analysis and management have to be used. Managerial decisions in complex systems must be comprehensive, consistent and scientifically based. Therefore, it is proposed to create a Decision Support System (DSS) consisting of modules, each of which will perform its function using all of the above methods.

When developing acceptable variants of logistic chains, Vehicle Routing Problem takes an important place [13, 14]. This is especially important in transition to green logistic, because in this case factors that influence the ecological situation are also added to a wide range of factors that need to be considered when routing and scheduling. In various studies, such factors as speed [15], the weighted load [16], traffic load on the route and their complex influence on different objective functions (apart from such usual ones as logistics operating costs and transportation time): either fuel consumption [17], total CO₂ emissions [18], or their combinations [19] were considered. The paper [20] provides decision support methodology that unites network science, green logistics and transportation accessibility research. A detailed presentation and description of studies that consider the problem of "green" vehicles routing can be found in the research of [21]. When planning spare parts delivery reasonable transportation mode selection is the priority task. The authors of the article [22] have considered such alternatives as rail, truck and air mode of transport, but this study does not consider the possible options for intermodal transportation. At the same time, globalization lengthens supply chains so that companies tend to expand their production patterns offshore or source from more distant locations [23], the use of intermodal transport can provide cost effective solutions for long distance transport needs of the supply chains, as well as for reverse logistics. Moreover, the use of terminal transportation will reduce overruns and minimize the concentration of harmful emissions along the main roads due to the breaking up the delivery lots into smaller units.

Intermodal transportation can ensure the benefits of each mode of transport used in the supply chain. However, in this case companies face such problems as the lack of coordination at the various intermodal transfer points, causing delays. That is why intermodal technologies not only include physical movement and terminal handling technologies but also cover the information and communication technologies required for coordination [24, 25]. Moreover, the use of different modes of transport for one shipment requires technical

solutions for fast transfers from one vehicle to another. There are several different technologies for solving this problem. They are containerization [26], swap bodies [27], the so-called KAMATEYNER (project of the plant KAMAZ), etc.

The widespread of the Internet of Things and additive technologies can make significant changes both to production logistics and to the supply chain management. According to Gartner Inc. (NYSE: IT), the leader in the sphere of information technologies researches, the impact of Industry 4.0 on supply chain management will subsequently manifest itself in the four key aspects [28]:

- creation of intelligent factories (production) based on flexible automated processes. Such enterprises will be integrated with each of the stakeholders' groups and will cover each of the stages of the product life cycle;
- virtual production on the basis of Internet of Services, requiring the creation of new business models, changing the existing design of supply chains;
- predictive analysis based on Big Data, which will allow flexibly managing all the processes, not just the production lines themselves;
- usage of intelligent production, in which the complexity of machines and technologies will require focusing on employee's knowledge, skills and engineering excellence at every stage of the supply chain.

Identification of inventory items, which makes it traceable in the production process and the entire supply chain, is the most important task of Industry 4.0. This allows determining the responsibilities of each of the participants of the supply chain and the production process, as well as ensuring return or recall defect product. Another opportunity to satisfy the increasing demands of consumers for environmental friendliness and product's safety is reliable and objective information on the origin of components (raw materials) and its constituents, which can be implemented using "smart chips". Thus, according to all forecasts and estimates, the impact of neo-industrialization on supply chain management and logistics as a whole will be very significant.

3. RESULTS AND DISCUSSIONS

3.1 Creation of a unified information environment for production, logistics and service management

Globalization of automotive markets, the emergence of Assembly plants in different countries, changing business management concepts and responsibility of the manufacturer for its products throughout the life cycle - so global companies create their own branded logistics and service systems. Public corporation (PC) "KAMAZ" is a major manufacturer of trucks with a high level of production localization and is the basis of transport security in Russia. The company dominates the Russian truck market and plays a significant role in export markets, has a developed system of corporate service: authorized dealers, retail outlets, shops and warehouses not only in Russia but also in other countries.

One of the goals of dealers in this network is to create the effective sales and distribution network of the genuine spare parts in the regions, to minimize the deficit of spare parts and provide the fastest delivery to the clients. The

spare parts are shipped directly from KAMAZ plant stocks in different quantities and different transportation modes depending on the type and location of dealer's warehouse. To ensure effective work with dealers, a logistics system has been created. Its tasks are: improvement of supply chain management, increase in the share of suppliers of "A" category to 80%, long-term contracts, logistics automation, end-to-end supply chain, development of new lines of business (such as Internet sales, telematics, "product as a service").

On the map (Fig. 3), the plant-manufacturer PC "KAMAZ", located in the Naberezhnye Chelny city, Volga Federal District, as well as some points of its spare parts' sales and automobiles' service are marked. In this region, in December 2015, the first stage of the Sviyazhsky Interregional Multimodal Logistics Centre was launched. It is located on the intersection of the two main Euro-Asian transport routes "East - West" and "North - South", therefore it has access to the federal transport mains of rail, water, motor transport in the future.

The Sviyazhsky terminal combines transportation by road, rail and water, which creates good prerequisites for the formation of alternative supply chains, and makes it the core of the transport and logistics system of freight transportation in the Volga Federal District. The Sviyazhsky terminal can become a major transshipment point for export-import cargo in all regions of the Volga Federal District, as well as a hub river port for transporting goods along international transport corridors.

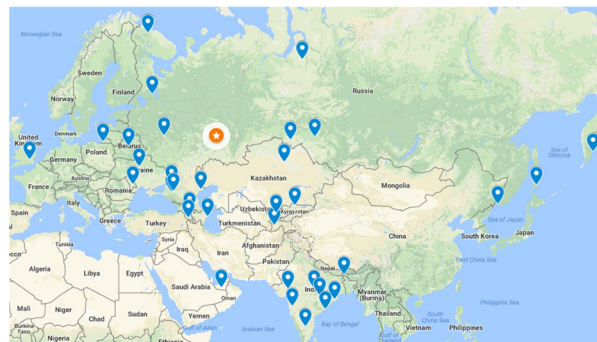


Figure 3. Location of some of authorized dealers and warehouses of PC "KAMAZ"

For trucks, when creating a dealer service network (DSN) in the regions, the following scheme is often used: a large dealer service centre (DSC) of the A type is in the centre of the "bush" and there are DSCs of B or C types (depending on the features of location) on the periphery of the "bush" (Fig. 4). In this case, as a rule, standard DSC formats are used. For a large service centre of the A type, the number of workstations varies from 13 to 30. The B type, as a rule, has from 7 to 12 workstations, the C type - from 2 to 6 workstations.

Type DSC influences the area of a warehouse, accordingly and the nomenclature of spare parts differs (Fig.4).

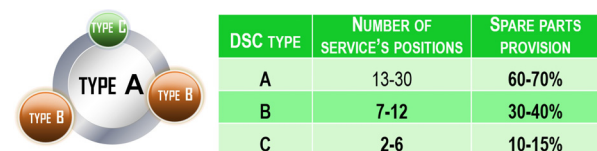


Figure 4. Types of Dealer Service Centres

DSC category A have a store for the sale of spare parts, so there is a warehouse in which spare parts for sale are stored. The second part of the warehouse has spare parts for the service. The mechanisms of replenishment of stocks on these two parts of the warehouse differ. The warehouse of spare parts for sale is oriented to seasonal needs, and the warehouse for the service is formed depending on the species-age structure of the vehicle fleet.

The united information space serves to organize feedback and manage material and information flows in the general system of the corporation, which consists of production, logistics, including reverse, and service subsystems (Fig. 5). At present, based on the data on premature failures and requests' statistics, a forecast model of spare parts needs is being formed in the DSC, which varies both for different regions and for different DSC. In accordance with these models, supply chains have also been formed, as well as resupply models.

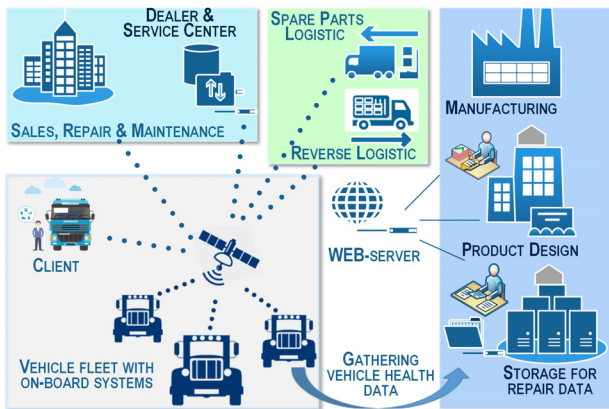


Figure 5. Information flows and interaction of subsystems of the automotive corporation

Since decision-making is based on the real data of the object under management, both analysis and adopting of strategic decisions require aggregate information available from a specially created data storage (DS). Data storages contain the information collected from several operative databases of an on-line transaction processing systems (OLTP). The core of DSS a corporative service system is a multi-dimensional intelligent data model (an OLAP cube) which collects stores and formalizes the parameters of dealer and service network (Fig. 6).

For implementation of OLAP cube the hybrid option has been chosen. Hybrid OLAP is a combination of both ROLAP (Relational OLAP) and MOLAP (Multidimensional OLAP). This ensures higher scalability of ROLAP and faster computation of MOLAP. HOLAP servers allows storing the large data volumes of detailed information (Fig. 7).

System administrator refreshes data in dimension tables, and adjusts the fact table, if new queries are necessary for users. Reporting Services (SSRS) allows creating reports for a large number of data sources. This service has a full range of tools for creation, management and delivery of reports. SSRS has API interfaces that help developers to make integration or to expand possibilities of data processing and reports in user applications.

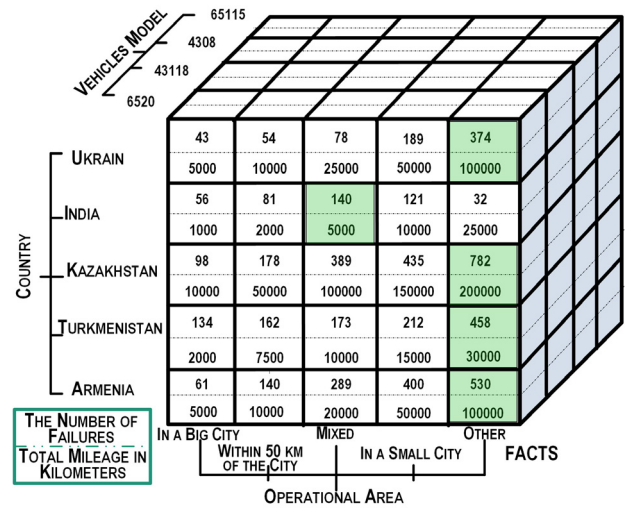


Figure 6. One of OLAP-cube's variants

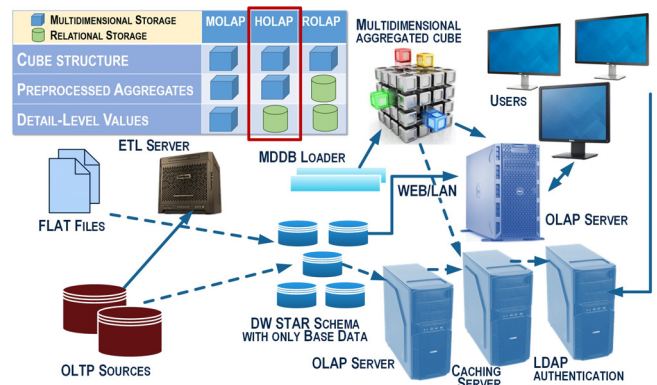


Figure 7. Types of OLAP technology implementations

The Reporting Services tools are completely integrated with the SQL Server tools and components [29-31]. This architecture was a basis for creation of the program module that allows output data on all possible measurements of an OLAP-cube for the intelligent analysis.

3.2 Logistic system of the Public Corporation "KAMAZ": organization of spare parts delivery

Since PC "KAMAZ" has a developed system of branded services, which includes regions' dealer and service networks, as well as a logistics system that solves the problem of delivery of spare parts: for example, the urgent delivery of the necessary part for warranty service if it is not in the warehouse, planned delivery of replenishment of the warehouse, etc.

The choice of the delivery method is determined by the geographic location of the subjects and many other factors (cost, urgency, season, risk, etc.).

At the vehicles' operation stage, which is the longest of all life cycle stages, the main requirement of customers is to maintain the vehicles in a technically sound condition. Since the owner of the vehicle needs servicing, it is necessary to do in the shortest possible time.

The research has been devoted to developing of the process optimization techniques. The manufacturer has to provide a prompt replacement of the failed unit for the customer to get back a serviceable vehicle to perform logistics operations and obtain profit. The most

important in the organization of customer service is the warranty period. Therefore, it is important that during this period the customer does not have problems with the vehicle. If buyer of the vehicle detects failure during the warranty period, he addresses to the nearest branded autocentre.

During maintenance, it is often necessary to replace certain parts. The replacement can be done using the customer's spare part or by selling it to the customer from the branded autocentre's storehouse. In the second case, the master has to issue a "Defect Sheet", which lists the required spare parts and their required quantity. Spare parts supplies management is carried out by analysing data from reclamation reports, according to which the most appropriate law for failures distribution is being built and an optimal supply plan is calculated.

DSS records the flow of service requests, the analysis of which allows building the laws of time distribution between receipts of requests, as well as the time of the vehicles' stay at the repair station. These distribution laws are compared with similar laws of the previous period, which allows determining the state of the system and adjusting management process. Therefore, if the time between requests has increased, this may indicate a drop in services demand. The increase in the time of the vehicles' stay at the repair station can be caused by the lack of spare parts, as well as inefficient organization of the technological process.

One of the problems in planning the operation of closed-loop logistics network is the difficulty in estimating the volume of defective parts, so for effective planning and coordination it is necessary to improve the quality of the forecast. For this, the territory covered by the logistics network is divided into areas in accordance with the categories of operating conditions: type of road surface, type of terrain, temperature and humidity, etc. The frequency of vehicle malfunctions and, accordingly, the frequency of occurrence of defective parts can be divided into three stages of operation. For each region, the dependence of the probability of vehicle failure on the mileage is built. Choosing the law of failures distribution is a separate task. So, some researchers use the Weibull distribution law [32, 33].

However, as a result of statistical treatment of truck failures in the Kazakhstan Republic territory, we found that the exponential distribution is the most statistically significant, the density of it has the form:

$$f(x) = \lambda e^{-\lambda x}, \quad x \geq 0 \quad (1)$$

where x - failure interval, km; λ is a parameter numerically equal to the intensity of the failures' number.

Fig. 8 presents the obtained distribution laws depending on the identified climatic zones in Kazakhstan.

Because the stochastic nature of the occurrence of defective parts is difficult to take into account in the mathematical model, we decided to build a simulation model. For this, in AnyLogic simulation environment using the agent approach, a closed logistics network of PC "KAMAZ" was built. A motor vehicle in operation, a service center, warehouses of all levels, the manufacturer, as well as vehicles used for the delivery of spare parts are considered as agents. The transition from a

"workable" state to the "repair required" state is determined by the established dependencies of the probability of a vehicle's failure on the mileage. The results obtained after the run of the model showed its viability and made it possible to establish optimal modes of spare parts supplies [34]. Since currently there is insufficient data on reverse flows, the verification was performed on model data based on statistical data and information about the possibility of repair and rebuilding.

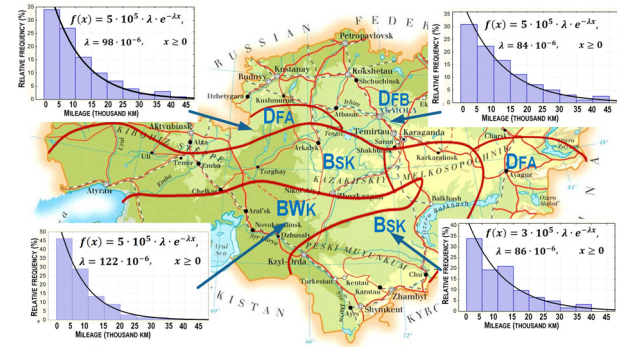


Figure 8. Obtained failure distribution laws

3.3 Models and algorithms for managing the vehicles' workability

When the customer contacts the service center, the employee prepares a report on the identified defects, according to which repairs are carried out. At this time, defective parts may also form, which make up the reverse logistics flow, which are currently being stored in the service center.

To improve the planning efficiency of the spare parts delivery structure and time, it should be taken into account that different aggregates, units and systems of a truck have different useful lives and different levels of reliability that, in turn, depends on numerous stochastic factors. The vehicle's failure occurs at the time point T_{fail} that can be predicted with a certain probability. As it is shown by analysis of operational indicators, the vehicle's failure rate $\lambda(t)$ can be divided into three operational stages [35]. Failures are the most frequent in the initial operational period (during the running-in stage), and are usually caused by manufacturing defects. During the regular operation, failures are accidental and emerge suddenly, largely due to non-compliance with service conditions, overloading, exposure to adverse external factors, etc. The third period is characterized by increasing failure rate caused by ageing and other factors connected with long operation.

Considering the previously mentioned, the mechanisms of spare parts supply must be functionally different. Since the warranty period is crucial in securing the customer loyalty, a high-quality service during this period is a priority. Although it is hardly possible to fight failures at the running in stage, one can analyse defect statistics to reveal the spare parts with the high possibility of premature failure. To ensure uninterrupted service at this stage, there has been developed the mechanism for calculating the qualitative and quantitative structure of the warranty spare parts set (WSPS) to be forwarded together with the next party of vehicles

to the region of their operation. Since during the regular operation, failures are largely dependent on operating conditions and are stochastic in nature, predicting of the spare parts demands is based on the dependencies established from analysis of failures that are detected during the client's arrival in DSC. The WSPS are needed for timely replacement of spare parts, if failure happens at the running-in stage; their contents are specific for each region and formed using special techniques allowing to eliminate the greatest number of failures in the sold group of trucks likely to occur during the warranty period. The cost of WSPS is decided upon by the manufacturer and may not exceed certain reserve amounts, which is needed for warranty repairs and is equal to a percentage of the cost of each vehicle sold, which was determined by the manufacturer. The method is based on multi-criteria analysis of failure statistics.

The main problem in this case is that a large number of models and modifications of vehicles and frequent updating of the model range make it difficult to obtain adequate information on failures. In addition, the warranty period often includes not only the running-in stage, but also the beginning of the standard operation phase, for which WSPK is not provided, for example includes manufacturer's risks. This requires the development of methods for predicting possible customer requests based on a study of the probability of failure of different components depending on the vehicle mileage and age. This method serves as the basis for the formation of spare parts kits' structure, calculates the date when you need to replace specific parts, and creates the delivery schedule in the logistic management centre. The problem's mathematical formulation consists in balancing between the costs to urgent delivery of spare parts required but not available in the warehouse and the cost of storing surpluses in DSN warehouses [36]. We have supposed that the spare parts kit has this volume: $q(i, j)$ ($i=1..N, j=1..M$). It must be distributed from the logistic management centre in M foreign regions, where N is the total number of nomenclature units in spare parts kits. Deliveries are carried out by sets of the i -th name of a spare part, which can be considered the aggregated nomenclature.

The reserves' level at the logistic warehouses is reduced in accordance with λ_{ij} , which is the failure rate of the i -th details, aggregate, or system in the j -th operational region. Delivery takes place either on the deliveries date τ , which depends on the distance between the j -th operational region to logistic management centre, or by reducing the inventory level k_{ij} in DSN reserve to the critical values S_{ij} of the i -th component. In this case, the kit's size is equal to q_i , and the costs should aim to minimize the g_{ij} . At random demand, the total number of deliveries B for the period (year) is estimated. Storage costs and penalties are calculated on the expected reserve (deficit) by the period end. The penalty is determined by the probability of deficit. DSC pays the cost h_{ij} of storage in the warehouse of spare parts of the i -th name for the whole period and delivery g_{ij} size of the spare parts kit. If the reserve does not allow satisfying all requests, it leads to the customer's lost profit. Therefore, the DSC pays a penalty for the deficit. The fine includes excess of the cost of

unexpected delivery over the usual and the percentage of "frozen" working capital due to deficit.

$$d = \sum_{i=1}^N \sum_{j=1}^M \left(\frac{\lambda_{ij} B^2}{2g_{ij}} - \frac{1}{h_{ij}} \right) \quad (2)$$

The time, volume and structure of the spare parts kit are selected to minimize the total cost. At the same time, maximum size of delivery should not exceed the capacity of the warehouse, and its cost - the specified total cost. The objective function will be the following:

$$Z = (\tau - t_D) \cdot Z_1 + B \cdot Z_2 + Z_3 \rightarrow \min \quad (3)$$

where:

$$\begin{aligned} Z_1 &= \sum_{i=1}^N \sum_{j=1}^M \lambda_{ij} h_{ij} k_{ij} \\ Z_2 &= \sum_{i=1}^N \sum_{j=1}^M g_{ij} q_{ij} \\ Z_3 &= \sum_{i=1}^N \sum_{j=1}^M d_{ij} (S_{ij} + q_{ij}) p_{ij} \end{aligned} \quad (4)$$

Limitations are:

$$\begin{aligned} \sum_{i=1}^N \sum_{j=1}^M d_{ij} \sum_{i=S}^{\infty} p_i - h_{ij} &\geq 0; \\ \sum_{i=1}^N h_{ij} - d_{ij} \sum_{i=S+1}^{\infty} p_i &\geq 0 \end{aligned} \quad (5)$$

Delivery time is:

$$\tau_j = \sum_{i=1}^N \left(\left(\frac{q_{ij} + S_{ij}}{\lambda_{ij}} - t_D \right) + g_{ij} \cdot B \right) \quad (6)$$

The efficiency indicator can be the average downtime of customers waiting for spare parts:

$$v_j = \sum_{i=1}^M \frac{p_{ij}}{\Lambda_j}, \quad (7)$$

where p_{ij} is the average number of query to replace a faulty of the i -th part in BSA the j -th region; the total flow of serviced requests:

$$\Lambda_j = \sum_{i=1}^N \lambda_{ij}. \quad (8)$$

Because the cost of the warranty will not exceed the amount of the reserve, then the target function of forming WSPK is to minimize the total cost of shipping and storage spare parts, penalties amounts due to the lack of spare part required (lost profits of the customer). Its price and labor costs for repairing the unit are also taken into account. The method of forming WSPK has two main phases: the distribution reserve amount of the vehicle in accordance with the statistics of failures in the region; volume-cost analysis for each vehicle to clarify the spare parts kits in WSPK.

In view of limitation on the integral cost of spare parts, it is hardly possible to create large initial stocks of

modules that would guarantee the availability of any spare part should it be needed. On the other hand, lacking SP in the WSPS may protract the service time. Considering this, a balance should be found between the costs of WSPS storage and urgent delivery to minimize the costs. This can be achieved by the use of specialized software that would effectively organize the logistic processes in the branded service system. The selection algorithm, incorporated in the model, presupposes the availability of several options of cargo delivery along each of the routes. A great number of factors that can affect both the quality and time of delivery characterize each of the routes. Besides, deliveries along the multi-link chains may take longer time due to uncoordinated operations of different modes of transport and transfer units.

So, an important task in interaction with foreign dealers is planning of spare parts deliveries, which depends on the critical level of parts in DSC warehouses and determined by the point of time when the level of stored parts either falls below the minimum (t_{k1}) or will be reduced to zero (t_{k2}) before order is executed.

In the norms of storage of a certain resource in a certain warehouse, there are t_1 and t_2 indicators that determine the acceptable values of critical levels. t_1 - deadline for delivery planning; t_2 - deadline for the start of the delivery planning process (depending on the region of operation). Possible criticality levels are shown in table 1.

The critical level of 1-2 implies that no correction of the delivery schedule is needed; by 3-4 the schedule must be corrected. The level of 5-6 signifies a high probability of certain parts missing in the DSC warehouse in case of failure. This signifies that the schedule is to be immediately corrected and alternative ways of delivery are found.

Table 1. Criticality Levels

LIMITATIONS VALUE (T_k)	LIMITATIONS		
	$T_k < T_1$	$T_1 \leq T_k < T_2$	$T_2 \leq T_k$
T_{k2}	6	4	2
T_{k1}	5	3	1

If the database contains ready-made optional solutions, it is possible to make selection from the available variants; otherwise, solutions are searched by the use of simulation. The model limitations are:

$$\begin{aligned} \sum_{i=1}^N m_i \cdot n_i &\leq U_l, \\ \sum_{i=1}^N v_i \cdot n_i &\leq V_l, \end{aligned} \quad (9)$$

where m_i - weight of the i -th name of spare parts, kg; U_l - carrying capacity of the l -th vehicle used for deliveries to a given region, kg; v_i - physical volume of the i -th name of spare parts, m^3 ; V_l - capacity of the l -th vehicle used for delivery, m^3 .

3.4 Choosing a delivery vehicle

In the formation of logistics chains, it should be borne in mind that the most problematic are road transport.

This is due to a large number of restrictions. Trucks' spare parts (TSP) transportation includes a whole set of requirements to the vehicle fleet, traffic capacity, road surface conditions, as well as cargo safety, because the possibility of the oversized and overweight loads transportation can be limited by the size and load (bridges capacity, the size of tunnels, the presence of railway crossings, electric transmission lines and communications, and even by the weather conditions and the season of the year). A vehicle that exceeds the legal dimensions usually requires a special permit, which requires extra fees to be paid in order for the oversize/overweight vehicle to legally travel on the roadways. The permit usually specifies a route the load must follow as well as the dates and times during which the load may travel. This concerns delivery of the TSP both within the country and in the case of international cargo transportation.

During TSP transportation, all the most important and significant factors must be taken into account. That means that when planning, attention is focused on developing the most rational solution for cargo transportation, which allows to minimize costs, and to perform the task as soon as possible. To plan a transportation, it is necessary to have in mind their following characteristics:

- type of the vehicle's body must suit the type of the cargo;
- which sections of the road network, as part of the route, are allowed to transport goods with such characteristics;
- the cargo must be delivered on time, as breaking the agreed deadlines disrupt obligations to customers DSC.

The purpose of planning transportation by road vehicles' is to minimize the total number of vehicles involved in the transportation process and the total distance of transportation.

$$F = \sum_{k \in V_M} \sum_{(ij) \in U} C_{ij}^k \times X_{ij}^k \rightarrow \min, \quad (10)$$

where C_{ij}^k - the cost of transporting goods along the route ij by vehicle k ; M - type of vehicle; V_M - the number of vehicles of the same type (in terms of carrying capacity and body type).

$$X_{ij}^k = \begin{cases} 1 & \text{if trip from point } i \text{ to } j \\ 0 & \text{if trip from point } j \text{ to } i \end{cases} \quad (11)$$

$$C_{ij}^k = C_{Mstand} \times (q_{carr} \cdot \gamma_{carr})_M \times n_{iM} \times V_M \quad (12)$$

where C_{Mstand} - cost (ton-kilometre) of transportation for a vehicle of type M , q_{carr} - load-carrying capacity; γ_{carr} - load factor.

Total number of voyages of type M vehicles:

$$n_{iM} = \sum_{k=1}^V n_{iM}^k \quad (13)$$

Number of trips per vehicle:

$$n_{iM}^k = \left[\frac{T_{iM}}{t_{ij} + t_{ji} + t_{load} + t_{unload}} \right]^k \quad (14)$$

where T_{iM} – daily working time; t_{ij} – direct voyage; t_{ji} – return voyage; t_{load} – loading time; t_{unload} – unloading time.

Limitations:

$$\begin{cases} T_{iM} \leq T_{norm} \\ W_{cargo} \leq q_{carr} \\ V_M \geq 0 \text{ and unit} \\ \gamma_{carr} \geq 0.8 \end{cases} \quad (15)$$

$$X_{ij}^k \times (q_{carr} \cdot \gamma_{carr})_M \times n_{iM} \times V_M = Y \quad (16)$$

where Y – service network need for spare parts.

$$X_{ji}^k \times (q_{carr} \cdot \gamma_{carr})_M \times n_{iM} \times V_M = \%_r \cdot Z \quad (17)$$

where $\%_r$ – the proportion of defective parts and end-of-life vehicles to be collected (in this case, it is taken based on the storage capabilities of the existing network without expansion due to additional investments); Z – a number of defective parts.

3.5 Formation of closed-loop supply chains

Since the direct and reverse logistics flows are interconnected, their joint design in the form of integrated logistics networks is not only logical, but also advisable.

Analysis of the studies showed that many researchers paid attention to the construction of conceptual models and optimization of reverse logistic channels for end-of-life vehicles [38, 39]. At the same time, the recycling of metal parts is one of the most developed areas. Networks for collecting parts from other materials are still at the initial stage of creation, so the development of recycling of non-metallic fractions is an urgent task today. The relevance of this problem is increasing because many automakers use carbon fiber to lighten the weight of the structure. So in the study [40], the solution to the problem of reverse logistics for end-of-life vehicles in German closed supply chains was simulated. In this paper, the concepts of designing networks for the separation and recycling of plastic components in collection and proces-

sing centers is considered. An illustrative case study on the disposal of damaged beyond repair tires in the southern states of Brazil is presented in [41], while issues of the reuse of vehicle glazing are addressed in [42].

The authors of the study [32] presented a network model for the disposal of used vehicles, which takes into account revenue from the sale of reusable parts and scrap metal, taking into account the costs of transportation and network building. Have focused on the expected volume of deductible vehicles in 2022 a forecasting structure of the logistics network was considered.

It should be noted that one of the overriding question is assessing the capacity of repairing and recycling centers, therefore the author of [43] studied approaches to solving the problem of the location of collection centers and considered network layout options that would effectively take into account 100%, 90% and 75% of the total market coverage.

For all the variety of aspects involved in organizing reverse logistics, existing studies are limited to consideration of end-of-life vehicles, not taking into account defective parts that occur in large numbers directly during the operation of the vehicle. In addition, as mentioned at the beginning of the paragraph, the planning of forward and reverse logistics flows must be carried out together. Therefore, the volume of the reverse logistic flow Z , representing defective parts, was introduced into the mathematical model of spare parts delivery (formula (17)).

In the transition to the "closed-loop economy", defective parts form "return flows", which can be of three types, depending on the further use (Fig. 9):

- for repair. They are sent to the warehouse after recovery and in the future can be used for vehicles' maintenance;
- for remanufacturing. They are stored separately, and if it is a dealer centre of B or C type, these items are sent to the larger warehouse of A type dealer centre for storage. When there are enough items to form the delivery lot, they are sent to the manufacturer by the return trips of vehicles, thus excluding empty runs;
- for recycling. They can be stored and transported in an extruded form to save space.

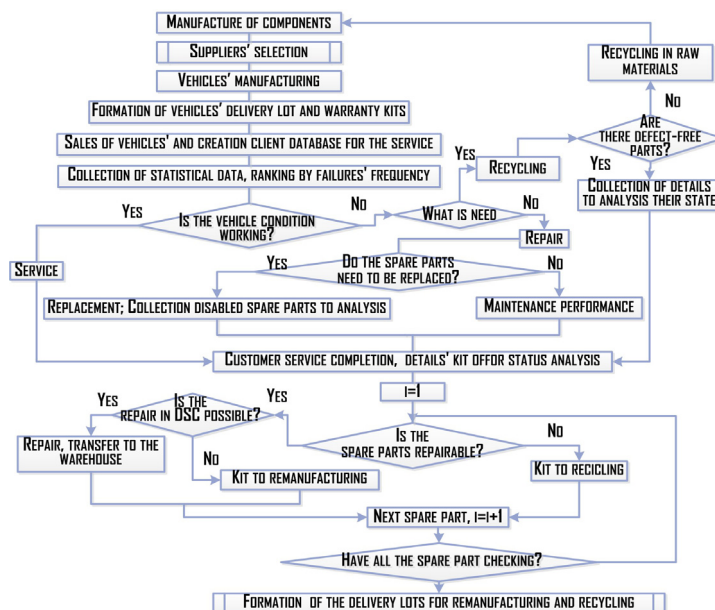


Figure 9. Algorithm of spare parts delivery including reverse deliveries for remanufacturing

Since the components of the vehicle are heterogeneous both in the material from which they are made and in the possibility of disassembling the structure, determined by the maintainability indicator, which affects the possibility of its recovery and disposal, the next step is the clustering of defective parts according to the main systems of the vehicle. After processing the collected statistical data on clients' contacts to the service centers of the KAMAZ firm service network, we obtained such laws for various operating conditions of vehicles (Fig. 10) [37].

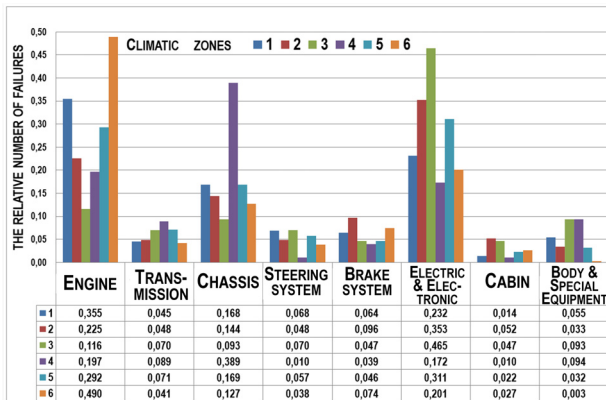


Figure 10. Distribution of relative number of vehicles KAMAZ aggregates failures in countries of different climatic groups (1-6)

In addition, at the design stage, manufacturer currently has the ability to determine the maintainability of each node, unit and vehicle system, which will make it possible to predict the operation of the service system and the return logistics even before the sale of the product.

Further, for each group of parts, the possibility of repairing in the service network, sending it to the factory for remanufacturing, or sending it for recycling with further use as secondary raw materials, or disposal is determined (table 2). Thus, in the proposed model, for the first time, the parameters of backflow formation, differentiated for various operating conditions and vehicle subsystems, are introduced.

When solving the problem of setting up a direct and reverse logistics network, the manufacturer must solve next issues:

- the proportion of defective parts and end-of-life vehicles to be collected (It depends on the capacity of existing storage centres);
- the proportion of parts suitable for secondary operation after repairing in the service network / suitable for secondary operation after remanufacturing at the factory / suitable only for recycling / disposed of (It is determined by the condition of the defective parts and technological capabilities of restoration of the service network and the manufacturer);
- the proportion of vehicles and spare parts sold through direct logistics channels consisting of only new components / consisting of a set of new and restored components / consisting of only restored components. (It is established based on the analysis of the relevant market segments capacity. In this regard, it is forward-looking approach to use a modular product design to create an

initial product and obtain lower recovery costs by reducing the lead-time and simplifying the overall recovery process).

To assess the effectiveness of the proposed approach, we simulated the return of defective parts of the main vehicle system - the engine. The choice of this unit is due to the highest failure rate among vehicle systems, along with the chassis and the electrical and electronic system (Fig. 11).

In addition, the analysis of the average indicators for the degree of suitability for recycling showed that engine parts are among the most promising in terms of reuse reserves after refurbishment at the factory, not currently in use, as well as in the form of secondary raw materials.

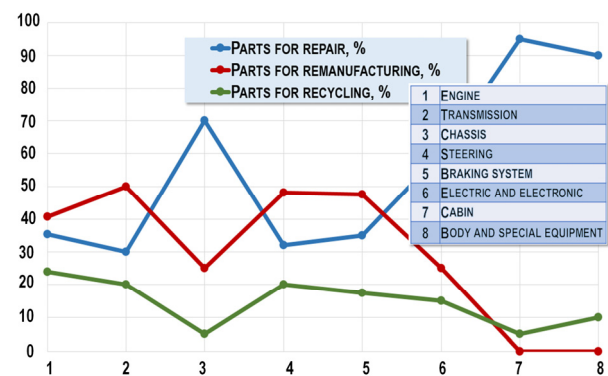


Figure 11. Average index of reuse suitability for vehicle systems

According to the customer service rules of the firm service network, defective parts formed during the warranty period are the property of the manufacturer, and after its end - the property of the vehicle owner.

An analysis of actual clients' contacts to service centers showed that in 62% of cases, customers do not take a defected spare part due to its uselessness. As a result, these cases, as well as the entire volume of warranty defective spare parts, can be considered as lost profits of the firm network in the absence of an established mechanism and production and technical infrastructure for reuse.

The results of modeling the restoration of engine system parts for KAMAZ 5490 during the warranty period showed the feasibility of introducing the of reverse logistics principles even without taking into account the reduction of environmental load in the form of saving raw materials (Fig. 12).

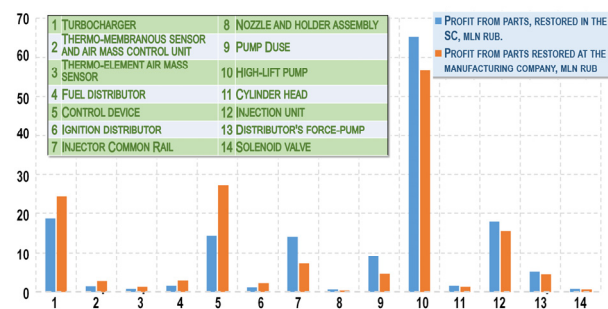


Figure 12. The profit when implementing the reverse logistics principles for the engine system of the KAMAZ 5490

Table 2. Distribution of the ratio of recycling options for the main vehicle systems

VEHICLE SYSTEM	A PART	PERCENTAGE OF DEFAULTS IN THE VEHICLE SYSTEM, %	PARTS FOR REPAIR, %	PARTS FOR REMANUFACTURING, %	PARTS FOR RECYCLING, %
ENGINE	Turbocharger	10	30	50	20
	Hot-film air mass sensor and control unit	2	22	47	31
	Hot-wire air-mass sensor	2	22	47	31
	Fuel distributor	1	22	47	31
	Control Unit	1	22	47	31
	Ignition distributor	1	22	47	31
	Common Rail Injector	3	52	30	18
	Nozzle and Holder Assembly	3	52	30	18
	Unit Injector	3	52	30	18
	Common Rail High-Pressure Pump	7	40	39	21
	Cylinder Head	3	40	39	21
	Unit Pump	3	40	39	21
	Distributor Injection Pump	3	40	39	21
	Solenoid Valve	1	40	39	21
TRANSMISSION	Cardan Shaft	9	30	50	20
	Commercial Vehicle Clutch Components	20	30	50	20
	Pneumatic Clutch Actuation	5	30	50	20
	Dual-Mass Flywheel	5	30	50	20
	Torque Converter	15	30	50	20
CHASSIS			70	25	5
STEERING	Power cylinder	25	32	48	20
	Steering Pump	45	32	48	20
	Steering gear	18	32	48	20
BRAKING SYSTEM	Brake Caliper	17	90	5	5
	Compressor	15	40	45	15
	ABS-modulator	5	5	70	25
	ABS-/ESP-Electronic control unit	2	5	70	25
ELECTRIC AND ELECTRONIC	Starter	15	60	25	15
	Alternator	15	60	25	15
CABIN			95	0	5
BODY AND SPECIAL EQUIPMENT			90	0	10

4. CONCLUSION

World economic development trends indicate an increasing negative impact on the environment. At the same time, the practice of doing business shows that the linear model of the economy is inefficient. A positive impact on economic and environmental efficiency can be provided by a paradigm shift in economic development - the transition to a circular economy. In this case, manufacturers must change the logistics system. Reverse logistics will play an important role in such a system. Planning of supply chains should be based on complete information about the possibility of processing the product and restoring it. The article gives an example from the automotive industry. It is shown that it is possible to implement the transition to a circular economy with the help of planning logistic processes in the branded service system of the automotive corporation.

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**УЛОГА ОБРНУТЕ ЛОГИСТИКЕ КОД
ПРЕЛАСКА НА ЦИРКУЛАРНУ ЕКОНОМИЈУ:
СТУДИЈА СЛУЧАЈА ЛОГИСТИКЕ
РЕЗЕРВНИХ АУТОМОБИЛСКИХ ДЕЛОВА**

**И. Макарова, К. Шубенкова, П. Бујвол,
В. Шепелев, А. Грисенко**

Рад приказује начин на који се одвија индустријски развој у ери преласка са линеарног на циркуларни модел економије као и нови правац развоја логистике. Показана је узајамна повезаност процеса код производних система, логистике и услуга, њихове улоге у обезбеђењу одрживог зеленог раста. Такође је показано да затварањем круга животног циклуса производа обрнута логистика има значајну улогу у преласку на циркуларну економију. Дат је пример планирања залиха резервних делова када се организују услуге на страним тржиштима. Планирање се заснива на вишедимензионалној анализи неуспеха и моделирања података. У ту сврху развијен је информациони систем. Утврђене вероватноће неуспеха у одређивању обима залиха коришћене су за израду модела ланца обрнуте логистике у оквиру кога су по први пут уведени параметри формирања обрнутог тока диференцирани према различитим радним условима и подсистемима возила.