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OPTIMIZATION OF AUTOMOTIVE RECYCLING PREPARATION PROCESSES

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Keywords: process optimization, automotive preparation, recycling, innovative technologies, automation, robotics.
Abstract. This article explores the optimization of automotive recycling preparation processes, covering all stages – from procurement to dismantling. The challenges faced by companies in the recycling industry, such as high costs, inefficiencies at various stages, and environmental risks, are analyzed. The study examines the role of innovative technologies, such as automation and robotics, in enhancing the efficiency of these processes. Additionally, opportunities to improve logistics and methods for processing valuable materials are discussed. The article investigates how the adoption of modern technologies and management practices can reduce costs, enhance operational safety, and minimize environmental impact.

ОПТИМИЗАЦИЯ ПРОЦЕССОВ ПОДГОТОВКИ АВТОМОБИЛЕЙ К ПЕРЕРАБОТКЕ

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Ключевые слова: оптимизация процессов, подготовка автомобилей, переработка, инновационные технологии, автоматизация, роботизация.
Аннотация. В статье рассматривается оптимизация процессов подготовки автомобилей к переработке, включая все этапы – от закупки до разборки. Анализируются основные проблемы, с которыми сталкиваются компании в процессе переработки, такие как высокие затраты, неэффективность на различных стадиях и экологические риски. Исследуется роль внедрения инновационных технологий, таких как автоматизация и роботизация, в повышении эффективности этих процессов. Также рассматриваются возможности улучшения логистики и методов переработки ценных материалов. В статье исследуется, как использование современных технологий и методов управления позволяет снизить затраты, повысить безопасность операций и минимизировать воздействие на окружающую среду.

Introduction

Automotive recycling is a complex high-tech industry faced with many difficulties. Millions of vehicles are processed through recycling or dismantling operations every year in order to retrieve secondary materials, but the process is often criticized for its expense, inefficiencies at various points, and associated environmental risks-especially when current technologies and practices are not in use.

One of the main tasks of the modern industry is to maximize the processes of all stages of automotive recycling preparation, starting from procurement and ending with dismantling. The reduction of recycling costs, improvement of operational safety, and minimization of environmental impact are impossible without the implementation of new approaches and technologies. Automation, robotic systems, improved logistics, and advanced methods of processing valuable materials not only raise the level of process efficiency but also reduce time and financial expenses. The objective of this paper is to analyze the main stages in the preparation of automotive recycling and to identify at each stage an opportunity for optimization.

Main part. Overview of the current state of the automotive recycling industry

During the last decades, car recycling has evolved as a global activity that strives to minimize the impact on the environment it causes from a car once it has reached its end-of-life phase. Originally, its primary focus was mainly on metal recycling to enhance the use of secondary metals. However, as technology improves and the environment policies become more stringent, the horizon for today is much broader. Preparing vehicles for recycling involves several interrelated stages, each requiring meticulous organization, considering technological, environmental, and economic factors (fig. 1).

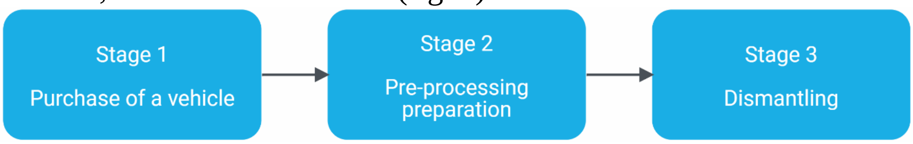

Fig. 1. The process of preparing vehicles for recycling

Vehicle procurement for recycling is the first link in the chain, which determines the efficiency of all further operations. The sources of vehicles can be very different: dealerships, insurance companies, private individuals, as well as companies specializing in fleet recycling and vehicle decommissioning. Each of these channels has its own characteristics: dealerships and insurance companies often supply damaged vehicles that require repairs but still hold value for recycling [1]. On the other hand, private individuals often provide vehicles reaching the end of their life cycle, with lower profitability related to the recovery of secondary materials; however, the scrap metal value compensates for it.

Vehicle procurement involves evaluation of the vehicle condition and its residual value. The factors of essence in the assessment are the age of the car, wear and tear, and whether damage is present that could reduce the potential profit to be derived from recycling. Logistics also plays a very important role in assessing transportation costs, cost of delivery of vehicles to the recycling facilities, and storage costs at intermediate locations. To ensure maximum efficiency, the vehicle procurement system requires a well-structured interaction framework with suppliers and optimization of the procurement process to minimize costs.

One challenge at this stage is procurement inefficiency, which can arise from errors in vehicle condition assessments or suboptimal logistics. Vehicles imported for recycling originally often prove to be less profitable than initially projected because of the cost of transport or expense required to rehabilitate usable components that could be resold on the secondary market.

Once vehicles arrive for recycling, they need to be **prepared for further dismantling**. This stage involves inspection and diagnostics to identify hazardous substances, such as oils, batteries, antifreeze, refrigerants, and other fluids that may pose contamination risks [2]. Preliminary diagnostics are also conducted at this stage to assess the wear and tear of various vehicle components and identify potentially valuable materials that can be recycled for reuse. Despite existing technologies and even strict standards, the technological processes of removing the toxic components tend to be incompletely effective. Some problems on the safety issues of general ecological cleanness might arise as soon as particular outdated technologies already can't comply with modern standards of the environmental environment; incomplete automation is threatened with disorders from an environmentalist viewpoint and affects health.

The **dismantling stage** is a critical part of the recycling process, during which vehicles are disassembled to extract valuable materials and components. This process can be categorized into two main types: manual disassembly and automated dismantling, each suited for different vehicle conditions and end-use goals.

Manual disassembly involves detailed, labor-intensive work, requiring skilled personnel and specialized tools. It is particularly effective for newer vehicles, where components retain high market value and can be resold as spare parts. This method allows for careful extraction of various elements, including electronic modules, smaller engine components, and interior fittings, maximizing the reuse potential of high-quality parts.

Automated dismantling, on the other hand, is more suitable for older vehicles where a significant portion of materials is destined for recycling rather than resale. This process relies on heavy machinery, such as cranes and hydraulic systems, to quickly extract large components like engines, transmissions, and structural elements. It is an efficient approach for large-scale operations, facilitating the separation of metal, plastic, and other recyclable materials. However, the high capital investment required for automation, including equipment and maintenance costs, can pose challenges for smaller businesses in the industry.

The dismantling stage of recycling enterprises poses challenges in extracting certain components, which are either hard to separate or recycle. For instance, components made of composite materials, complex elements such as air conditioning systems, or electronic devices, call for more accurate disassembly methods and often more expensive recycling technologies [3]. Some vehicle parts might be contaminated, thus necessitating pre-cleaning before dismantling.

Optimization of processes at each stage of automotive recycling preparation

The optimization of automotive recycling processes plays a significant role in improving efficiency and reducing both environmental and economic costs. Each link in the chain requires a tailored approach, taking into account modern technologies and innovative management methods. To enhance the efficiency of procurement, it is recommended to **implement a forecasting system** that can more accurately predict the volumes and types of vehicles entering the recycling process.

Such a system may incorporate market condition data, information on vehicle life cycles, and statistical modeling and data analysis to forecast the flow of end-of-life vehicles. This would allow for the early optimization of storage and transportation capacities, as well as improved cost planning.

An important aspect involves the **development of contractual relationships with vehicle suppliers** to ensure stable supplies and improve confidence in the quality of incoming vehicles. Long-term contracts with large dealerships, insurance companies, and government institutions managing fleets can provide more favorable terms for both parties.

To further improve procurement efficiency, attention should be given to **adopting automated procurement systems**, such as blockchain technology for transaction tracking and transparency, as well as creating electronic platforms to optimize supplier interactions [4]. This would not only speed up the procurement process but also ensure quality control and adherence to delivery schedules.

At the pre-recycling preparation stage, the focus should be on ecology, safety, and cost optimization related to the storage and disposal of toxic liquids and components. One approach is the **use of environmentally friendly technologies for the removal of toxic substances**. Closed-loop systems can be implemented to minimize pollutant emissions and improve cleaning efficiency. **Using advanced technologies for fluid purification**, such as filtration and distillation methods, can not only reduce disposal costs but also improve environmental safety. For instance, systems for recycling antifreeze and oils using chemical processes or membrane filtration enable the extraction of useful components, reducing environmental impact and the need for new resources.

Attention should also be paid to **optimizing storage and transportation capacities**, which can lower the costs of storing toxic materials. Implementing automated systems for managing inventories of toxic liquids can reduce handling time and improve control over their condition, ensuring safety and compliance with regulatory standards.

To improve dismantling efficiency, **robotic systems** should be introduced to perform tasks related to component extraction. The use of robots can significantly reduce dismantling time, increase the precision of component extraction, and lower risks for workers. Robots can operate in hazardous or hard-to-reach areas where traditional dismantling methods may be inefficient. The application of robotic systems also reduces the likelihood of damaging components, thereby increasing their market value in the secondary materials market.

Improved logistics are essential for dismantling efficiency, from transporting vehicles for recycling to moving extracted materials. This may involve optimizing transportation routes, utilizing automated warehouse systems, and enhancing coordination between recycling stages. Automation in material storage and handling minimizes downtime and accelerates processing.

The incorporation of **Lean Manufacturing** and **Six Sigma** methodologies in automotive recycling processes significantly improves overall efficiency, reduces costs, and increases quality at all stages. The Lean methodology involves waste minimization and process optimization by eliminating non-value-added activities and improving task execution speed. The application of this approach in automotive recycling includes optimization of transport flows, improvement in the organization of workspaces, and reduction in equipment and staff downtime.

Six Sigma, however, is the process of improvement of quality and elimination of defects at every step. Statistical methods and data analysis are used to find out the bottlenecks in the processes. Low material recovery rates or failure to meet environmental standards are bottlenecks. Interestingly, together these methodologies not only improve the dismantling and recycling processes but also enhance customer satisfaction by delivering high-quality final products.

Thus, the optimization of processes at every stage of automotive recycling preparation requires a comprehensive approach. This includes the adoption of new technologies, improvement of logistics and inter-stage coordination, and the application of modern management methods to increase overall efficiency. This approach not only contributes to economic benefits and improved environmental conditions but also plays a vital role in social aspects (tab. 1).

Tab. 1. Benefits of optimizing automotive recycling preparation processes [5, 6]

Stages of the recycling process	Economic advantages	Environmental benefits	Social benefits
Car purchase	Reducing logistics costs by forecasting supplies, optimizing purchases, and reducing losses when buying cars.	Reducing emissions of pollutants during transportation, reducing the need for recycling damaged vehicles.	Job creation through infrastructure development and contractual relationships with suppliers, increasing supply stability.
Pre-processing preparation	Reducing the cost of storing toxic liquids and components, efficient use of equipment for the extraction and disposal of liquids	Reducing soil and water pollution by safely removing toxic liquids and components and using environmentally friendly technologies	Ensuring the safety of employees through automation, improving working conditions, and preventing exposure to toxic substances
Dismantling of cars	Reduce time for disassembling through mechanization of activities, and increased recovery of worthwhile components by applying robotic systems	Reducing waste, improving the sorting of materials, recycling hard-to-recycle components, and reducing environmental pollution	Improving the working conditions of employees through the introduction of robotic systems, reducing the risk of injury and improving the quality of the work environment

Thus, the optimization of processes for preparing vehicles for recycling, which includes the implementation of innovative technologies, improvements in logistics, and the application of modern management methods, has a significant impact on economic, environmental, and social aspects. These achievements are confirmed by the practices of large companies actively employing comprehensive approaches to optimize automotive recycling processes.

For instance, **Schnitzer Steel Industries, Inc**. employs robotic systems and automated lines to extract valuable metals from vehicles. Such technologies speed up the dismantling process and enhance the accuracy of material sorting, thus reducing costs and increasing profitability. The company also employs logistics optimization techniques to optimize the transportation of vehicles and materials [7]. The company uses advanced technologies for inventory management and supply forecasting, which help in reducing storage costs and improving the overall recycling process.

Another example is the experience of **LKQ Corporation**, which applies advanced methods for material processing and sorting, including improved technologies for restoring auto parts and recycling materials. The company is actively involved in the recycling of vehicle batteries and refrigerants, which helps to reduce its negative impact on the environment and adhere to ecological standards [8].

These examples demonstrate how the integration of modern technologies and management practices can not only improve the economic efficiency of automotive recycling but also deliver environmental and social benefits, highlighting the importance of a comprehensive approach to process optimization.

Conclusion

Optimizing processes for the preparation of vehicles for recycling is another critical point of influence on the efficiency of the industry in general. The introduction of modern technologies connected with automation and robotics, and also the methodology of Lean and Six Sigma, might significantly improve the production processes, decrease costs, and improve profitability. These technologies contribute to more effective extraction of valuable materials, waste reduction, and lower environmental impact. Additionally, process optimization helps create safer working conditions, minimizing risks to workers and improving the social environment within the industry.

However, to achieve maximum economic, environmental, and social benefits, a comprehensive approach must be taken. This includes not only technical innovations but also improvements in logistics, procurement processes, and coordination between recycling stages. As demonstrated by the examples of leading companies, these efforts provide significant advancements in automotive recycling, confirming the effectiveness of comprehensive optimization and its importance for the sustainable development of the industry.

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