Selection of Optimization Criteria for the Commercial Vehicle Manufacturing Process with a View to Minimizing the Carbon Footprint

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ABSTRACT

This article focuses on the issue of reducing the carbon footprint in manufacturing companies, with particular emphasis on the automotive sector and the production of commercial vehicles. It presents the key methods for calculating the carbon footprint, such as Life Cycle Assessment (LCA), energy and fuel consumption analysis, and greenhouse gas emissions reporting standards (GHG Protocol and ISO 14064). It then discusses selected methods for optimising production processes: Theory of Constraints (TOC), Six Sigma and Lean Manufacturing. Particular attention is paid to the Lean Green concept, which integrates measures to improve process efficiency with environmental objectives. Based on an analysis of production processes at MAN and Scania plants, key criteria influencing the carbon footprint were identified, including production tools, internal transport, workstation equipment and lifting equipment. These are intended to form the basis for developing a methodology for optimising commercial vehicle production processes, with particular emphasis on resource utilisation and carbon footprint levels.

KEYWORDS: *carbon footprint reduction, commercial vehicles, optimization criteria, optimization of production processes*

1 INTRODUCTION

The world's population is constantly growing, and as a result, so too is the demand generated within the global economy. This situation applies to all goods, both luxury items and essentials, such as food. International and domestic trade, in turn, means that the transport sector must constantly evolve. This presents new challenges for humanity, linked to an ever-increasing carbon footprint. The European Green Deal and the regulations adopted under it mean that the transport sector must seek optimisation solutions to minimise its impact on the environment, particularly its carbon footprint.

2 CARBON FOOTPRINT – A BRIEF OVERVIEW AND METHODS OF CALCULATION

The carbon footprint is currently one of the most important indicators used to assess human impact on the environment. It represents total greenhouse gas emissions expressed as carbon dioxide equivalent, meaning that a single indicator also accounts for other greenhouse gases such as methane (CH_4) or nitrous oxide (N_2O) and their impact on global warming [1].

Methods for calculating carbon footprints have been evolving since the beginning of the 21st century. The main aim is to provide reliable information on greenhouse gas emissions and to identify areas where these emissions can be reduced. In practice, various calculation methods and approaches are used, differing in their level of detail, scope of analysis and requirements for input data.

2.1 Life Cycle Assessment

One of the most important methods is Life Cycle Assessment (LCA). This method provides a comprehensive analysis of the environmental impact of a product or service throughout its entire life cycle – from the extraction of raw materials, through the production process, transport and use, to recycling or disposal [2].

This analysis consists of several stages. The first is to define the goal and scope of the analysis. Next, a material and energy balance for the process is drawn up, taking into account all raw materials used and emissions generated during production. The next step is an environmental impact assessment, which involves calculating, among other things, the level of CO_2eq emissions [2]. LCA is considered one of the most comprehensive methods. However, its disadvantages include the time-consuming nature of the process, as well as the need to collect very detailed data on the entire supply chain.

2.2 Analysis of energy and fuel consumption

Another commonly used approach involves analysing energy and fuel consumption. In this case, it is necessary to determine the amount of electricity, gas and other fuels consumed. These figures are then multiplied by emission factors, which specify the amount of carbon dioxide produced when a given quantity of fuel is burned or a given amount of energy is generated [3]. In this way, a carbon footprint can be calculated quickly and easily. However, it should be borne in mind that this method does not take into account the full life cycle of the product or indirect emissions associated with the production of raw materials and services.

2.3 Greenhouse gas emissions reporting standards

Methods that comply with international standards for greenhouse gas emissions reporting are becoming increasingly important. Among the most significant are the Greenhouse Gas Protocol and ISO 14064.

The ISO standard contains information on the quantification, monitoring and reporting of greenhouse gas emissions [4]. The implementation of such standards is often part of companies' sustainability strategies and a requirement under European Union legislation.

The GHG Protocol is the most widely used standard adopted by businesses and public institutions worldwide. Under this framework, emissions are divided into three scopes. Scope 1 comprises a company's direct emissions, i.e. those resulting from the combustion of fuels in facilities or vehicles owned by the company. Scope 2 covers emissions associated with purchased electricity or heat. The final scope covers other indirect emissions, such as those associated with transport, business travel or the production of raw materials [5].

Although there are many different approaches to calculating a carbon footprint, there are a number of challenges associated with this. One of these is the availability of reliable emissions data across the entire supply chain. Businesses often do not have accurate data on the processes carried out by their suppliers. The development of renewable energy sources also means that emission factors require frequent updating.

3 APPROACHES TO OPTIMISING PRODUCTION PROCESSES

Process optimisation is an integral part of the operations of modern manufacturing companies, which face increasing pressure from competitors, rising costs and ever-changing customer requirements. To stay ahead of the competition, companies must continually improve their processes. To this end, they implement a variety of methodologies for optimising production processes.

3.1 Theory of Constraints

One such approach is the Theory of Constraints (TOC), developed by Eliyahu Goldratt. It is an organisational management approach focused on identifying the factors that limit the achievement of the desired outcome. According to this methodology, every production system has at least one constraint that determines its overall performance. This constraint may be physical, organisational, technological or market-related [6].

The essence of the Theory of Constraints is therefore to increase the throughput of the entire production system by effectively managing its weakest link. The first step is to identify the constraint. The next step is to maximise its production potential. Subsequently, all other processes should be subordinated to the operation of the constraint. If the implementation of the earlier stages has not yielded acceptable results, the capacity of the constraint should be increased through investment or process reorganisation. If the bottleneck in question is successfully removed, the cycle begins again, as a new bottleneck arises somewhere in the production system [6].

One of the most important tools used in TOC is the DBR method, which aims to synchronise the entire production process with the capacity of the bottleneck. It consists of three elements:

- Drum – determining the system's operating rhythm,
- Buffer – ensuring the continuity of operations at the bottleneck,
- Rope – controlling the flow of materials into the process.

Unlike other production optimisation methods, the Theory of Constraints focuses on the performance of the entire production system, rather than on the local efficiency of individual workstations. This approach is particularly effective in companies struggling with frequent production delays, capacity issues or uneven resource utilisation.

3.2 Six Sigma

Another methodology used by many companies is Six Sigma. This concept was developed in the 1980s at Motorola. Its main aim is to reduce process variation and minimise the number of errors and non-conformities. The name Six Sigma refers to the concept of standard deviation (sigma), which is used in statistics and, in a quality context, denotes 3.4 defects per million opportunities for error [7].

Empirical and statistical data form the basis of Six Sigma. The key to solving a problem lies in identifying the root causes of quality issues and eliminating them in a systematic manner. The DMAIC cycle is most commonly used [8]:

- Define – defining the problem
- Measure – measuring process parameters,
- Analyse – analysing the causes of non-conformity,
- Improve – implementing improvements,
- Control – monitoring results.

The implementation of Six Sigma brings tangible economic benefits to businesses by reducing the number of complaints and cutting costs associated with production defects, whilst also having a positive impact on process stability. This methodology is also frequently integrated with Lean Manufacturing due to convergence of their objectives and the tools they employ, giving rise to the concept of Lean Six Sigma, which combines the elimination of waste with the reduction of process variation.

3.3 Lean Manufacturing

Lean Manufacturing, as mentioned earlier, is one of the most important concepts in production management. It aims to maximise value added for the customer whilst minimising waste. Lean Manufacturing was developed at Toyota's plants, and its development was driven by the need to increase production efficiency with limited resources [9].

The fundamental principle of Lean Manufacturing is to maximise the value delivered to the customer whilst eliminating all forms of waste occurring in the process (known as 'Muda'). There are seven types of waste [9]:

- Overproduction,
- Waiting,
- Unnecessary transport,
- Over-processing,
- Excessive stock,
- Unnecessary movement,
- Quality defects.

An eighth type of Muda is also often identified, namely untapped human potential [9].

Lean Manufacturing is based on a number of fundamental principles, the application of which streamlines production processes. The first step is to define value from the customer's perspective. Next, the Value Stream is analysed. The next step is to ensure a smooth flow within the company and to implement a pull system, in which production takes place in accordance with the actual demand of external or internal customers. The final element is the pursuit of process improvement [9].

The Lean Manufacturing methodology employs a number of tools that support the organisation and optimisation of processes. These include [9]:

- Kanban system – used to control the flow of materials,
- 5S – enables the proper organisation of workstations,
- VSM – value stream mapping,
- Standardisation of work,
- Poka Yoke – solutions designed to minimise the likelihood of operators making mistakes.

4 THE DEVELOPMENT OF THE LEAN GREEN CONCEPT – COMBINING THE OPTIMISATION OF PRODUCTION PROCESSES WITH THE REDUCTION OF THE CARBON FOOTPRINT

The current climate situation and issues relating to resource scarcity mean that existing approaches to optimising production processes are no longer sufficient, particularly in the transport sector. It is not enough to improve processes in terms of organisational and economic efficiency; environmental efficiency must also be taken into account. There is increasing talk of the Lean Green approach, which combines the principles of Lean Manufacturing with environmental concerns. Organisations must respond to regulatory pressure and customer expectations regarding sustainable production. More and more markets and contractors require compliance with specific environmental standards, and investors are increasingly choosing companies that demonstrate a genuine commitment to the environment. The current objective is therefore to minimise waste in processes and reduce the consumption of energy, raw materials and water.

4.1 Choosing the best approach

At present, companies are primarily focusing on reducing energy consumption by making changes to their infrastructure, such as sealing and minimising losses in compressed air systems, replacing lighting with energy-efficient alternatives or using more efficient machinery for the same tasks, as well as switching to renewable energy sources and reducing the amount of waste generated. However, the carbon footprint can be reduced through both changes to infrastructure and changes to the production process.

In order to enable staff responsible for planning commercial vehicle production processes to take the carbon footprint into account, it is necessary to develop a methodology for optimising commercial vehicle production processes, that focuses on minimising resource use, which will, in particular, enable the reduction of the carbon footprint generated during the preparation and execution of product manufacturing processes.

To this end, it was necessary to draw up a research plan setting out the steps required to develop the methodology.

The first step involved conducting a literature review on methods for determining carbon footprint levels and selecting the most appropriate approach for calculating it in the specific type of production processes and products under analysis.

The next step was to review the literature on methods for optimising production processes in terms of their effectiveness and efficiency, which could be applied to the manufacture of commercial vehicles.

The results of this analysis have been presented in the previous sections of this article. In light of the above information, the best approach would be to combine the Lean Manufacturing approach, which focuses on improving the efficiency of virtually all processes within a company, with an environmental approach aimed at optimising the carbon footprint generated by the production process and its preparation. The best method for calculating a carbon footprint is to follow the approach set out in the international GHG Protocol standard.

4.2 Selection of criteria for optimisation

In order to properly develop optimisation tools within the framework of the methodology being developed, the most important step is to define the optimisation criteria that can significantly influence the carbon footprint generated during the production of commercial vehicles. It is advisable to base such decisions on actual production processes. It

was therefore decided to analyse the production process at the MAN production plant in Niepołomice. The production line there includes light, medium and heavy-duty trucks, ranging from two to five axles.

The study analysed the types of processes carried out on the production line and in the sub-assembly areas, as well as the types of tools and equipment used during the production processes. In addition, attention was paid to the organisation of material flow between individual areas. On this basis, it was determined that, in the case of the commercial vehicle production process, the following criteria may affect the amount of carbon footprint:

- Used fastening tools,
- In-plant transport,
- Logistics and assembly trolleys,
- Production area equipment,
- Lifting equipment, including slings.

These criteria were established on the basis of an analysis of the production process at a single company. To confirm that these criteria would also be relevant for other manufacturers, they had to be validated against the production process for vehicles of a different make. To this end, the production process of another leading commercial vehicle manufacturer, Scania, was analysed. During a study visit to the plant in Zwolle, which is the main production facility for this brand's trucks in Europe, the production process in operation there was analysed. Following this analysis, the above-mentioned criteria were deemed relevant not only to the specific production process at the selected company, but to commercial vehicle manufacturers in general.

4.3 Further steps planned for the development of the methodology

Once the criteria to be optimised have been selected, the next steps in developing the methodology are planned. The first of these is to collect data on the current and future commercial vehicle production processes. It is essential that the methodology is developed on the basis of real-world data. The data will be collected from one of Europe's leading truck manufacturers.

The next step will be to analyse the detailed data collected and develop a proposed methodology for optimising commercial vehicle production processes with a view to maximising their efficiency and effectiveness, including by minimising their carbon footprint.

Simulations of changes to the production process will then be carried out. These will enable an assessment of the effectiveness of the proposed methodology, and the potential benefits will also be analysed.

The results obtained will then be analysed in detail. It will be possible to make potential changes to the proposed methodology. In the next step, the changes to the production process will be simulated again and the potential benefits assessed.

This will result in the development of a methodology to support those planning commercial vehicle production processes. In this way, the carbon footprint can serve as a key optimisation criterion. The overall algorithm setting out the plan for our own work is shown in Fig. 1.

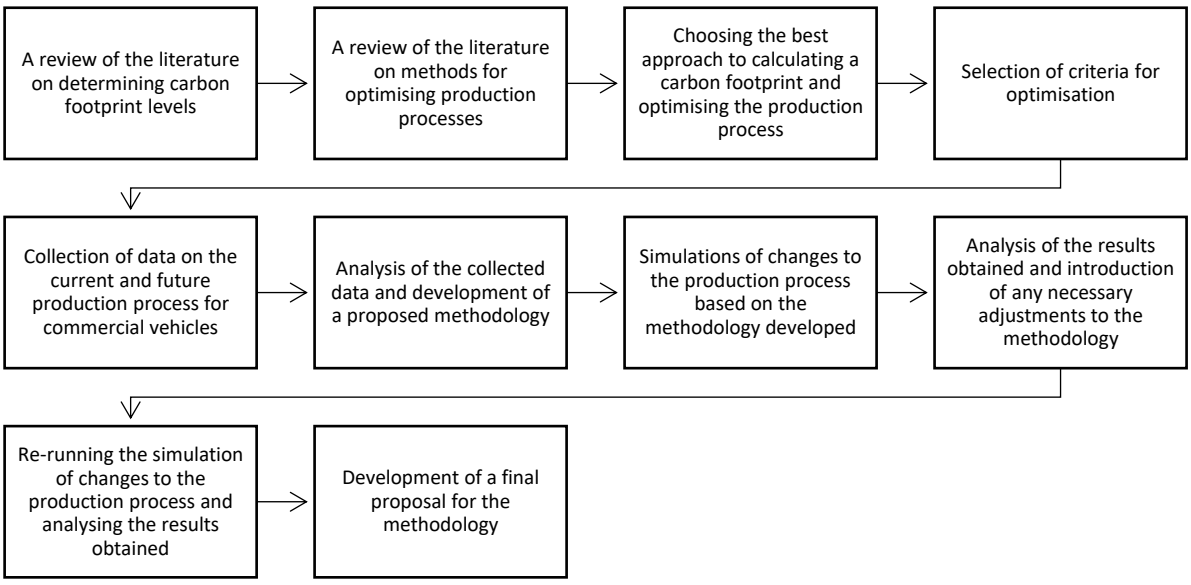

Fig. 1. Algorithm setting out the research plan. Source: own work

5 SUMMARY AND CONCLUSIONS

The optimisation of production processes in the commercial vehicle sector, when focused solely on organisational and economic efficiency, is no longer sufficient and must also take environmental considerations into account.

The article outlines the key methods for calculating carbon footprints. The following chapter also discusses methodologies for optimising production processes that are used in manufacturing companies.

It was concluded that the best approach to developing a methodology for optimising commercial vehicle production processes—one that focuses on resource use and carbon footprint—would be to combine the GHG Protocol's approach to carbon footprints with Lean Manufacturing principles for production process optimisation.

Based on an analysis of the production process at MAN and Scania plants, key criteria that may influence the carbon footprint were identified, including, amongst others, fastening tools, internal logistics, production area equipment and lifting equipment. The analysis, carried out at two independent production plants, indicates the potential for wider application of the methodology within the commercial vehicle manufacturing sector.

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