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Carbon and resource savings of different cargo container designs

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ABSTRACT

Currently, a huge amount of cargo is transported with maritime and road transport throughout the world. The majority of it is in cargo containers, which results in high environmental impacts caused by the transport and the manufacturing of the containers, such as depletion due to the large quantities of material used for the production of the approximately 18.6 million cargo containers in use globally. Another environmental impact is carbon emissions released in the production and use phases. One possible solution for more sustainable cargo transport is environmentally friendlier cargo containers, made according to eco-design principles. They are lighter, produced from less material with smaller environmental impact throughout their life cycle. This paper assesses the environmental impacts of a standard 20-foot cargo container with a simplified life cycle assessment study, focusing especially on green-house gas emissions. It reveals that up to 67% of all greenhouse gas emissions are related to material supply. A solution for environmentally friendlier cargo containers is seen in an eco-design dematerialisation strategy, with particular emphasis on the use of material and the production phase, but without compromising its performance. Three different designs of cargo container walls are assessed from an environmental perspective. Comparative analysis has shown a difference of approximately 15% in material use when comparing cargo containers with the highest and lowest impacts.

1. Introduction

When intermodal cargo container transport developed in the middle of the 20th century, the environmental perspective was not a key issue. However, nowadays, in a time of increasing population, high globalisation, dispersed allocation and scarcity of resources and regulatory frameworks (such as the International Convention for the Prevention of Pollution from Ships (MARPOL)), the environmental perspective has also gained importance in cargo transport. Over the past five decades, rapid increases in the concentrations of greenhouse gases in the atmosphere, mainly coming from the industrial sector, have resulted in global climate changes (IPCC, 2013). Consequently, cleaner and more sustainable production is becoming increasingly important within all industrial sectors (Klemeš et al., 2012; Mikulčić et al., 2015). Drewry (2015) estimates that approximately 21% of all cargo containers transported over the sea are empty. In addition to economic costs, this needlessly causes high environmental impacts that could be much lower if the containers were lighter (Konings, 2005).

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Therefore, the crucial environmental problem is the quantity and type of material used for the production of these seventeen million containers with particular attention on new ones. The production of containers and empty runs seem to be the two biggest environmental problems of cargo transportation (Levinson, 2006). Reducing the environmental impact of cargo containers is possible via designing and producing environmentally friendlier cargo containers. Due to increasing energy scarcity, seen especially in the EU, Cerovac et al. (2014) noted that it is also important to consider the energy sources used for their production.

To design environmentally friendly cargo containers, their environmental impact must be assessed with life cycle assessment (LCA), which has frequently been identified as an appropriate method for the comprehensive assessment of the environmental impacts of a certain product, because it evaluates environmental impacts through all phases of the life cycle, and it gives a good overview of numerous environmental impacts that are not immediately apparent. However, due to the high amount of data needed and included in LCA, it is an extremely complex and time-intensive method for evaluating environmental impacts. A review of the literature has revealed that numerous studies have been made on simplifying buildings and building material or different components, such as that of Kellenberger and Althaus (2009) on various levels of LCA simplifications or that of Bribian et al. (2011) focusing primarily on the embodied energy and global warming potential (GWP) of different materials. The study of Accorsi et al. (2014) was the only one identified dealing specifically with the LCA of cargo containers with a particular focus on multi-criteria optimisation of thermal liner containers in four instances of maritime shipments, also considering the environmental perspective. However, LCA is only the first step towards more environmentally friendly cargo containers, since it only reveals environmental impacts but does not minimise them. The next step is the use of eco-design tools, which enable the minimisation of environmental impacts identified with LCA (Obrecht, 2010). According to Gallagher et al. (2015) in some cases ecodesign can lead to cumulative savings up to 10.4% of GWP and can promote local materials and time savings in the production phase. Energy savings can even be seen in planning and designing efficient material handling and consequently increased energy efficiency (Lerher et al., 2014).

Lightweight construction could be a pathway towards sustainability. Although many ecodesign methods and tools are currently available, there is a gap in their integration into the design process in the industry, as well as in the daily practice of designers. According to Andriankaja et al. (2015), existing ecodesign methods are not always tailored to lightweight structures. Gerrard and Kandlikar (2007) foresee that the most substantial change in the design within the transport sectors is the design of new products, involving a change in the material composition: promoting the use of lightweight materials, extending the value of end of life (reuse and remanufacturing) and the improved provision of information. Simplifications of these methodologies are crucial for a comprehensive impact assessment and the minimisation of environmental impacts, because their outputs are easier to obtain and cheaper for the producers. Kellenberger and Althaus (2009) concluded that simplified approaches could lead to different ratings of various components or materials than a detailed assessment would, because certain data which contributes to some indicators are not taken into account. The accuracy of the simplified LCA method also depends on the indicator chosen for the study. Some indicators, such as GWP, are less influenced by simplifications as other indicators, such as cumulative energy demand, are. Therefore, it can be concluded that GWP is more appropriate for use as an indicator in simplified LCA because it is more concise and less influenced by simplifications than other indicators.

Based on the rather high environmental impact of cargo container transport, the lack of studies related to cargo containers environmental impact, and their design, this paper focuses on identifying new perspectives for possible improvements of cargo container's environmental performance. It focuses especially on comparative analyses of three different cargo container wall designs and a simplified life cycle assessment of their environmental performance with particular emphasis on the production phase, material use, and related carbon emissions, as well as their possible minimisation with different container wall profiles.

When using the eco-design approach with a special emphasis on one specific eco-design strategy, an analysis of environmental impact must first be used as the basis to determine which phases in a life cycle of a studied product have the highest environmental impacts. To design environmentally friendly products, all phases of a life cycle should be considered, and the best way to minimise product's environmental impact is with the implementation of the most appropriate eco-design strategies. However, this is usually not possible due to limited resources and restrictions related to the specific industry. Therefore, the identification of the most appropriate strategy is crucial to achieving the maximal improvements in a limited time and with limited resources.

2. Methods

This two-stage study combines environmental assessment and analysis of possible minimisations of environmental impacts with eco-design principles.

Specific data on cargo container measures, weights and the composition of materials was gathered from the International Organization for Standardisation (ISO) 20-foot dry intermodal cargo containers, constructed to withstand the stresses of intermodal shipping, handling and stacking according to ISO 6346 international standard (ISO, 2012). The 20-foot standard ISO container was selected as a functional unit. Calculations were also made to assess the 40-foot standard ISO container, because the majority of global cargo is being shipped with 20-foot and 40-foot standard ISO containers made of steel or aluminium. Two basic materials are compared to present possible material savings for aluminium as a light-weight and corrosion-resistant material and steel as a durable and cheaper material, which also requires less maintenance in the case of cargo containers.

2.1. Environmental assessment

Inventory data were gathered from ISO documentation on standard containers and production procedures. An environmental assessment was made with a simplified LCA. Therefore, results were presented with indicators related to carbon emissions: GWP and with the calculated mass of material used for the different cargo container types studied. The carbon footprint is adopted as a metric to assess the environmental impact of the container. Although the carbon footprint provides a limited view of the overall environmental impacts, and the comprehensive LCA method considers many impact categories (e.g. human health, resource preservation, and ecosystem quality), the carbon dioxide equivalent (CO_{2eq}) has been widely adopted for analysing and measuring the environmental performance of a certain product (Wright et al., 2011). We adopt the metric of Fitzgerald et al. (2011), which estimates that the emission of CO_{2eq} per maritime transportation of a standard ISO container reefer at 0.017 kg/tkm.

Given a particular product category, the LCA approach was applied for the 20-foot standard ISO container to identify the ratio of environmental impacts in different life cycle phases. Life cycle stages, impact categories, and system boundaries are presented in Fig. 1.

Fig. 1 presents the stages of cargo container life cycle and the system boundaries of simplified LCA, focusing especially on the raw material supply and manufacturing. LCA assessment includes all phases of the container life cycle. However End-of-life stage is additionally commented because different possibilities of reuse exist which can significantly prolong life expectancy of a container.

Usually, the most common solution is to start optimising phases with the greatest environmental impact. Because our goal was also to assess possible solutions for more sustainable cargo container transport, we first had to assess which phases are the most influential on environmental impact, and where the greatest opportunities for savings are in order to be able to identify the best ecodesign strategies for the minimisation of environmental impacts.

2.2. Comparative analysis and evaluation of improvements

The first (LCA) stage combines all stages of the container life cycle, and the second one (Eco-design stage) focuses on the dematerialisation strategy, because environmental impact analysis has shown that the raw material and production phase have the highest environmental impact. Therefore, the second stage of the study was focused on possible minimisations of these impacts with