ARTICLE IN PRESS

Int. J. Production Economics ■ (■■■■) ■■■–■■■

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Selection of pallet management strategies based on carbon emissions impact

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ARTICLE INFO

Article history:
Received 31 March 2014
Accepted 26 September 2014

Keywords:
Wood pallets
Carbon equivalent emissions
Single-use expendable
Reusable buy/sell program
Leased pallet pool

ABSTRACT

This work describes the lifecycle of wood pallets as they move through the supply chain and compares the environmental impacts of the three predominant pallet management strategies: single-use expendable, reusable buy/sell, and reusable leased pool. The pallet lifecycle is characterized in five phases: raw material sourcing, manufacturing, transportation and use, refurbishing, and end of life (EOL) disposal. Given that the useful life of a pallet and the environmental impacts that are generated during each phase of the pallet lifecycle vary, carbon equivalent emission functions are developed for each of the three pallet management strategies. The loading and handling conditions that pallets are subjected to as they move through the supply chain are considered as these greatly affect their useful life, and therefore have a significant impact on carbon emissions. In addition, an optimization model is developed to explore the effectiveness of blended or mixed pallet management strategies in minimizing carbon equivalent emissions under various loading, handling, and EOL scenarios. The findings suggest that no single pallet management approach is universally preferred in terms of minimizing carbon equivalent emissions. Under different handling, loading, and EOL conditions and different distribution distance requirements, any of the three available pallet management strategies may be preferred, or a combination of strategies may be required to minimize carbon equivalent emissions. This work can support decision making by logisticians and managers as they seek to minimize the carbon footprint of their operations by adopting practices and adapting the models to their specific conditions.

1. Introduction

As companies strive to make their supply chains more efficient and more sustainable they must evaluate every aspect of their shipping and distribution operations to understand their environmental impact. Pallets, being the most common unit load platform for handling and storing goods, are a critical component of these operations. Given the large number of pallets in circulation at any moment, they represent a significant investment for most companies and are likely to generate a significant environmental impact. Because large numbers of pallets are typically used when producing and distributing goods, the seemingly small environmental impact associated with the use of a single pallet is greatly magnified by the scale of the operations.

The Department of Transportation (Bureau of Transportation Statistics, 2009) estimates that transportation represents roughly 10% of the United States (U.S.) gross domestic product, or approximately $1.4 trillion. In 2006, some 8.8 million trucks traveled approximately 263 billion miles. Freight, in its many forms, accounts for 28% of total U.S. greenhouse gas emissions (U.S. EPA, 2010), 470 million metric tons of carbon dioxide equivalent ($MMTCO_2$) annually (7.8% of total US CO_2-eq emissions), and about 50% of NO_x emissions and 40% of particulate matter emissions from transportation sources (FHWA, 2010). Truck freight accounts for 70% of all these emissions. It is estimated that 80% of U.S trade is carried on pallets (Raballand and Aldaz-Carroll, 2007). Every year, approximately 450–500 million new pallets are manufactured and become part of the large pool (roughly 2 billion) of pallets that are in circulation in the U.S. (Buehlmann et al., 2009). Meanwhile, in the European Union, some 280 million pallets are in circulation every year. Within those, solid wood remains the most common pallet material accounting for 90–95% of the inventory and applications worldwide (Buehlmann et al., 2009; Mead, 2010). Traditionally, the pallet industry has been the single largest user of hardwood lumber in the U.S. by consuming between 33 and 50% (3.8 billion board feet) of

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http://dx.doi.org/10.1016/j.ijpe.2014.09.037
0925-5273/

Please cite this article as: Carrano, A.L., et al., Selection of pallet management strategies based on carbon emissions impact. International Journal of Production Economics (2014), http://dx.doi.org/10.1016/j.ijpe.2014.09.037

all the hardwood lumber (Buehlmann et al., 2009; McKeever and Dickerhoof, 1980). Many of these pallets are used only a few times and end up meeting a variety of end-of-life scenarios (e.g. landfill, municipal incineration or downcycling (e.g. wood pallet mulching for various applications) while others are refurbished and reused many times. It is estimated that pallets are responsible for 2–3% of all waste landfilled in the U.S. (Buehlmann et al., 2009). As companies set goals to become more sustainable, a thorough understanding of the environmental impacts of their pallet logistics becomes critical.

The manner in which pallets are managed throughout their lifecycle can produce a notable difference on the environmental impacts, as well as on the costs that arise from pallet operations (Bhattacharjya and Kleine-Moellhoff, 2013; Bilbao et al., 2011). In the U.S., the last two decades have seen an increase in the adoption of outsourced pallet management strategies with pallet take-back logistics. A rental model, sometimes called leased pallet pooling, or the alternative buy/sell programs have emerged as the predominant strategies in this category. These may allow companies to focus on their core business while outsourcing their needs and concerns for handling, sorting, refurbishing, treating and disposition of their pallets to a third party company. However, the environmental implications, in particular the emissions impacts, arising from these strategies are not yet characterized nor well understood. This work attempts to provide such insights. In particular, we aim to address the following research questions:

1. What activities, materials, processes, treatments and pallet designs encouraged and utilized by each pallet management strategy are the main contributors of carbon equivalent emissions in each LCA phase?
2. For a given weight of product that is required to be transported on pallets across the echelons of a supply chain, what is the optimal pallet management strategy and batch policy mix that minimizes the carbon equivalent emissions impact?

The remainder of the paper is organized as follows. In Section 2 we discuss literature on modeling carbon equivalent emissions for the product supply chain and systematic approaches to an environmental analysis of pallet lifecycle. We describe the life cycle of a wood pallet in Section 3 and present the scope and assumptions in Section 4. The data collection is discussed in Section 5. While Section 6 discusses the carbon equivalent emission coefficients for each lifecycle phase, the overall expressions for estimating the carbon equivalent emissions for the pallet management strategies are discussed in Section 7. The results and insights gained through the equivalent total emission functions are included in Section 8. A linear optimization model to determine the pallet management strategy mix based on multiple origin-destination pairs and flow requirements is presented in Section 9. Finally, the conclusions from this research are included in Section 10.

2. Literature review

Realizing the importance of not only minimizing overall supply chain costs but also minimizing the adverse environmental impacts from a supply chain function, researchers have developed models to estimate the carbon equivalent emissions at different phases of the supply chain. Such estimates of phase-wise CO_2 equivalent emissions are extremely valuable in analyzing tradeoffs and strategy selection. For example, Smith et al. (2005) and Browne et al. (2005) explained that by considering transport emissions along with production emissions, a distant but energy-efficient supplier may be preferred over a local but carbon-intensive supplier.

While little research has been carried out on measuring carbon equivalent emissions associated with the pallet supply chain, substantial research has been done on the product supply chain domain such as Fast Moving Consumer Goods (FMCGs). In this section, we review models on estimating CO_2 equivalent emissions for product supply chains. Koh et al. (2013) establishes the need for a state-of-the-art decision support system for carbon emissions accounting and management for a product supply chain (known as the supply chain environmental analysis tool (SCEnAT)). Sheu et al.(2005) propose a linear multi-objective programming model that systematically optimizes the operations of both integrated logistics and corresponding used-product reverse logistics in a given green-supply chain. The formulation considers factors such as the used-product return ratio and corresponding subsidies from governmental organizations for reverse logistics. Benjaafar et al. (2013) consider systems involving a single firm, as well as systems with multiple firms that operate either independently or coordinate their operations and carbon emissions. They consider several regulatory policy settings in a mixed linear integer program where (a) firms are subject to mandatory caps on the amount of carbon they emit, (b) firms are taxed on the amount of emissions they emit, (c) firms are subject to carbon caps but are rewarded (penalized) for emitting less (more) than their caps, and (d) firms can invest in carbon offsets to mitigate carbon caps. Daystar et al.(2014) analyze the cost and environmental impacts in the production of six regionally important cellulosic biomass feedstocks, including pine, eucalyptus, unmanaged hardwoods, forest residues, switchgrass, and sweet sorghum, using consistent life cycle assessment tools such as SimaPro 7.2 LCA software. Rizet et al. (2012) use benchmarking analysis to show that relatively high emissions occur for maritime transport and the consumer leg, while logistics activities such as storage and road freight exhibit relatively low emissions. Sundarakani et al. (2010) employ the Eulerian and Lagrangian transport models, which consider both active and passive tracers, to calculate the carbon emissions. Using this model they measure the carbon emissions in the supply chain that arise from various processes such the processing of raw materials to the dispatching of finished goods. Neto et al. (2008a,2008b) model the re-organization of the European pulp and paper logistic network using a multi-objective linear problem, with an objective function to minimize the network cost and environmental impact. The idea of exploring the best alternatives is based on Pareto optimality regarding economic and environmental goals.

When it comes to a systematic approach to an environmental analysis of a pallet lifecycle, only limited archival literature is available. Bilbao et al. (2011) conduct a comprehensive review of the activities that impact the environmental sustainability of logistics throughout the pallet life cycle. The impact of material choice by embodied energy, manufacturing emissions, phytosanitary (heat and fumigation based) conditioning treatments, as well as disposal are discussed but not assessed or quantified. Also, a model to select the appropriate mix of pallet type by material (hardwood, softwood or plastic) by means of a minimum cost multi-commodity network flow problem is proposed. Bhattacharjya and Kleine-Moellhoff (2013) highlight the key practices and sustainability issues in the management of the pallet life cycle in several regions of the world. This paper is also limited to a discussion of the issues and lacks quantification of the impacts or any other assessment. The physical flows of pallets under various management systems and return logistics have been described in literature (Harris and Worrell, 2008; Bilbao et al., 2011).

With respect to archival work on the individual phases of the pallet life cycle, several researchers have looked into specific aspects of each phase that may have an impact on environmental sustainability. Several studies have addressed different pallet end-of-life scenarios (Gasol et al., 2008; Bejune et al., 2002; Buehlmann et al.2009; Bush and Araman, 2008; Bush et al.,1997), which have provided insights on the specifics of a given end-of-life scenario. In particular, detailed studies on the final disposition fractions of wooden pallets by source and end-of-life destination are available