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Investigating the environmental and economic impact of loading conditions and repositioning strategies for pallet pooling providers

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ABSTRACT

Pallets are fundamental assets critical to worldwide supply chain logistics. This research develops models for closed-loop pallet pooling providers to understand the environmental and economic impact of customer characteristics and design options. First, an analytical model is developed to quantify the effects of repair facility location and pallet service conditions on a pallet pooling system's economic and environmental performance. Next, a simulation model is developed to investigate two common operational policies, crossdocking and take-back, and to quantify the impact of pallet handling and loading conditions and customer network structures on several key performance indicators. Results indicate that pallet handling and loading conditions are the most important factors determining the cost and carbon equivalent emission of a pallet pooling operation. Better pallet handling and appropriate loading increase the percentage of pallets that can be repositioned with little or no repair. This increases the radius within which a closed-loop pallet pooling system is feasible. Under random handling/loading conditions and distances, a crossdocking approach satisfies demand with 28% fewer pallets than a take-back policy. This is due to a quicker reissue time under a crossdocking approach. However, associated costs and emissions of the two policies are nearly identical due to the increased transportation costs associated with crossdocking. The models and insights proposed in this work can help support decision making by pallet pooling providers to determine operational regions and customer selection, among other network design trade-offs.

1. Introduction

Pallets are the most common platform for unit load formation, which enable seamless and efficient transportation of goods in supply chains. The importance of pallets and the extent to which supply chains rely on them are often underestimated: approximately 80% of the United States (US) trade is carried on pallets (Raballand and Aldaz-Carroll, 2005) and more than 2 billion pallets are in circulation in the US (Buehlmann et al., 2009). The European Union boasts more than 280 million pallets in circulation every year (Raballand and Aldaz-Carroll, 2005). The wood pallet and container industry is vast, complex and geographically dispersed. In the US, this industry, comprised of more than 2600 establishments, accounted for $7 billion dollars in estimated receipts in 2012 (NAICS, 2012). In spite of this, pallet logistics have not been extensively studied and the available scientific literature is limited. Given that 99% of the establishments engaged in pallet logistics are small businesses (The United States Census Bureau, 2016; Millwood Inc. 2015), industry data is generally not available. Because of this demographic, the bandwidth and resources to embark in these studies and models within the industry is almost non-existent.

Closed-loop supply chains have been defined in literature as "a special type of supply chains that consider the return flow of used materials in addition to the downstream flow of products" (Glock, 2017). Specifically, in pallet management, closed-loop systems allow the collection of used pallets at the end-point of the supply chain, for reuse, repair or recycling, as opposed to open-loop schemes, where the pallet remains at the final customer (Elia and

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Gnoni, 2015). A growing closed-loop model for pallet management is pallet pooling, where a service company (the pallet pooling provider) owns the pallets and manages their flows (Roy et al., 2016). Customers of the pallet pooling provider subscribe to access a pool of pallets to transport their goods. Under a pallet pooling scenario, pallets are generally collected after use at a downstream location in the supply chain (e.g. at the regional distribution center (DC) or retailer) by the pooling company or a network of regional pallet recyclers working in coordination with the pooling provider (Mazeika Bilbao et al., 2010). These collected pallets are processed and assimilated into the pool of pallet assets owned by the pooling company and further repositioned wherever needed (likely at an upstream location in the supply chain). The conditions of the pallets for immediate reuse may be inspected on-site at the docks during retrieval or after the pallets are transported to the recycler's repair depot. If the assessment of the pallet conditions is performed on-site, those pallets deemed in good condition for reuse can be immediately repositioned at a different facility while only pallets needing repair are transported to the repair facility for remanufacturing; a practice referred to as “crossdocking”. The alternate practice, referred to as “take back”, is to collect and all pallets from a customer's end point regardless of their condition and transport them to a repair facility for inspection, sortation, repair (if needed) and repositioning back into service.

Pallet pooling providers offer supply, management and tracking of pallet assets and have emerged as an alternative to companies who prefer outsourcing pallet management tasks to a third party. Pallet pooling providers operate a closed-loop system requiring decisions about how to best handle the reverse logistics required to backhaul pallets and pre-position them, as well as manage pallet repair and disposal activities. Previous research efforts have addressed decision-making aimed at improving pallet management performance, but consideration of a pallet pooling provider remains unexplored. The aim of this work is to investigate design and operational decisions from a pooling provider perspective, specifically repair depot locations, pallet loading and handling conditions, and pallet repositioning policies. Adopting both economic and environmental sustainability perspectives, the key performance indicators (KPIs) are economic costs and carbon equivalent (CO_2-eq) emissions associated with transportation and repair in a pallet pooling system. An analytical model focuses on used pallet collection, repair and repositioning, while a simulation model considers a broader supply chain perspective. In particular, take-back and crossdocking repositioning strategies are analyzed considering the impact of operational factors, such as pallet handling, loading and repositioning distances, being stochastic.

This paper is organized as follows. Section 2 contrasts our work with existing studies in pallet management literature, motivating the need to investigate pallet handling/loading conditions and repositioning strategies. Section 3 describes our research methodology and data sources. In Sections 4 and 5, the analytical and simulation models are presented and used to generate new insights related to closed-loop pallet pooling performance. Conclusions are presented in Section 6.

2. Literature review and scope of the work

2.1. Background on reverse logistics and closed-loops supply chains

Reverse logistics and closed-loop supply chain network design decisions have been studied from environmental, legal, social, and economic perspectives (see Govindan et al., 2015 for a comprehensive review). In particular, several studies focus on optimal location of remanufacturing and inspection facilities. For example, Alshamsi and Diabat (2015) elucidates the optimal selection of sites, the capacities of inspection centers and remanufacturing facilities, and selects between in-house vs. outsourced transportation. Srivastava (2008) develops a conceptual model for simultaneous location—allocation of facilities for a cost effective reverse logistics network. Others investigate the impact of product take-back recovery rate on the logistic network design decisions. For example, Fleischmann et al. (2001) investigate the impact of different product recovery rates on forward logistics network design on copier manufacturing and paper recycling. They show that product recovery can in many cases be implemented without many changes in existing forward production-distribution networks using a facility location model. Other logistics network design methods were also developed in the context of empty container repositioning in shipping liner networks and vehicle repositioning for car rental companies (For example, see Shintani et al., 2007 and Roy et al., 2014). While these studies attempt to minimize the overall logistics cost, they do not incorporate asset repair nor consider environmental impacts.

2.2. Literature on pallet management

Scientific literature focused on pallet management strategies and pallet supply chains is not vast, although interest has been growing over the last decade. Table 1 summarizes pallet management literature identifying four main research areas: (i) economic/environmental evaluation of pallet management strategies, (ii) environmental analysis of pallet operations, (iii) closed-loop pallet supply chain modeling and (iv) traceability in pallet management. These areas are contrasted with respect to the modeling approach, stakeholder perspective, KPI, decision level, problem addressed, method employed, and whether repositioning strategies or handling conditions are captured in the research.

Several authors focus on the *economic and/or environmental analysis of different pallet management strategies/operations*. Most of the works in this category have a specific environmental perspective. Gasol et al. (2008) perform a Life Cycle Assessment (LCA) to compare the environmental performance of different reuse intensity policies, pointing out the role that maintenance plays in reducing the overall impacts. Bengtsson and Logie (2015) perform an LCA to assess one-way and pooled pallet alternatives and demonstrate that pooled softwood pallets outperform all other alternatives. Carrano et al. (2015) explore different pallet management strategies, and provide an optimization model for minimizing emissions under several handling, loading, and EoL scenarios. Tornese et al. (2016) examine the pallet remanufacturing phase in great detail, performing a carbon footprint analysis to support decision making in this phase. This work highlights the importance of distance and handling/loading conditions on the environmental impacts of remanufacturing operations. Two works focus only on the economic dimension of pallet management: Roy et al. (2016) develop cost relationship models to compare open and closed-loop pallet management schemes from a user perspective, while Ray et al. (2006) compare the financial outcomes of rental and purchased pallets through simulation modeling, showing that renting can be more expensive. Finally, one work attempts to consider both perspectives in the evaluation of pallet management strategies: Mazeika Bilbao et al. (2011) model the environmental impacts of pallet management operations by developing a linear minimum cost network flow model to support decision making.

Research efforts focusing on the *environmental analysis of pallet operations* include: Bhattacharjya and Kleine-Moellhoff (2013) present an overview of sustainability issues in a pallet lifecycle, identifying the key stakeholder challenges. Carrano et al. (2014) analyze the carbon footprint of pallet operations for each phase of a pallet lifecycle, from raw materials to end-of-life (EoL),