



Cooperative coevolutionary approach for integrated vehicle routing and scheduling using cross-dock buffering



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ABSTRACT

Cross-docking technology transships products from incoming vehicles directly to outgoing vehicles by using the warehouse as a temporary buffer instead of a place for storage and retrieval. The supply chain management (SCM) with cross-docks is both effective and efficient where no storage is facilitated at the cross-dock and the order-picking is replaced by fast consolidation. However, cross-docking involves interrelated operations such as vehicle routing and vehicle scheduling which require proper planning and synchronization. Traditional cross-docking methods treat the operations separately and overlook the potential advantage of cooperative planning. This paper proposes a bi-objective mathematical formulation for the cross-docking with the noted new challenges. As the addressed problem is highly constrained, we develop a cooperative coevolution approach consisting of Hyper-heuristics and Hybrid-heuristics for achieving continuous improvement in alternating objectives. The performance of our approach is illustrated with real geographical data and is compared with existing models. Statistical tests based on intensive simulations, including the convergence 95% confidence analysis and the worst-case analysis, are conducted to provide reliable performance guarantee.

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1. Introduction

Logistics strategies are important competence for practicing the supply chain management (SCM) which requires delicate planning and alignment of intensive operations to reduce the cost while still providing satisfactory services. The classic SCM needs to transport the products from the suppliers to a distribution center or a warehouse for storage and then performs the order-picking based on the customer requests and ships the ordered items to the destinations. This form of SCM incurs high inventory holding cost for storage and laborious manpower for order-picking. The cross-docking distribution (Apte and Viswanathan, 2000), on the other

hand, becomes increasingly prevalent due to elimination of storage and order-picking by fast products-consolidation (usually less than 24 h) in the cross-dock terminal, which is used as a temporary buffer instead of a warehouse for storage and retrieval of goods.

Cross-docking is a logistics framework in which the inbound vehicles with loads of pickup products arrive at the receiving doors of a cross-dock and unload the products, these products are consolidated inside the cross-dock by using a forklift or a conveyor belt system and are directly reloaded into the outbound vehicles which then deliver the requested products to the destination customers. The operational economy achieved by cross-docking is guaranteed by the synchronization of inbound and outbound vehicles at the dock doors for the same product order, such that the storage at the cross-dock is needless and the order-picking is replaced by fast consolidation. Fig. 1 shows the logistics framework with cross-docking. Cross-docking has been applied to create core competence for many large-scale firms such as Wal-Mart, UPS, FedEx, Home Depot, Costco, and Toyota (Gue, 2001).

The distribution strategy performed by cross-docking entails several operational research problems for obtaining efficient logistics (van Belle et al., 2012), such those as vehicle routing, vehicle scheduling, dock door assignment, cross-dock location selection, and cross-dock layout design. This paper focuses on the scope of vehicle routing and vehicle scheduling problems from a system integration point of view, in contrast to previous

Abbreviations: SCM, Supply chain management; GrSCM, Green supply chain management; CO₂, Carbon dioxide; RFID, Radio-frequency identification; GPU, Graphics processing unit; AS/RS, Automated storage and retrieval systems; S/R machine, Storage and retrieval machine; FCFS, First-come first serve; EDF, Earliest deadline first; LLH, Lower-level heuristic; OVI heuristic, Objective-value improving heuristic; SFI heuristic, Solution-feasibility improving heuristic; HS method, Heuristic selection method; MA method, Move acceptance method; GA, Genetic algorithm; EA, Evolutionary algorithm; TS, Tabu search; SA, Simulated annealing; ACO, Ant colony optimization; GH, Greedy heuristic; IGVRSC problem, Integrated Green Vehicle Routing and Scheduling for Cross-docking problem; WCM, Weighting cost and makespan.

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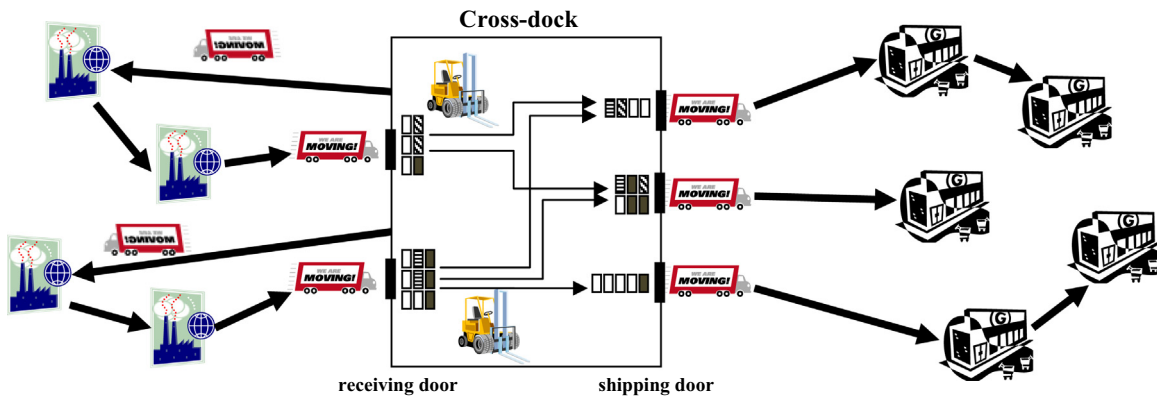


Fig. 1. Logistics framework with cross-docking.

researches which address the two problems separately. It is worth noting that most existing works assume the vehicles arrive at the cross-dock at the same time, so the vehicle scheduling is treated as an independent problem of the vehicle routing problem. However, in many cases the inbound vehicles arrive at the cross-dock along a time span. Classic vehicle scheduling approaches would have to deter the outbound vehicles from reloading until all the inbound vehicles arrive. This operation procedure overlooks the possibility for shortening the handling time if part of the vehicle scheduling can start earlier with the vehicles already waiting in the yard. Clearly, this new operation procedure needs an integrated approach for dealing with both the vehicle routing and vehicle scheduling, and this paper intends to provide such a solution.

Moreover, the social cognition of sustainable development has brought up the issue of the green supply chain management (GrSCM) which is not only environment-friendly but also beneficial to the business value. The GrSCM addresses the linkage between the natural environment and all materials produced and consumed in the SCM. Since 1990s, various topics have been contemplated such as green purchasing, green design, green manufacturing, green logistics, recycling, waste management, to name a few (Srivastava, 2007). As the production of carbon dioxide (CO_2) is the main cause of the global warming which has resulted in unbearable climate changes and disasters, this paper proposes a solution to the green logistics which transports the final products from the suppliers to the customers with minimal intensities of emitted CO_2 to the environment.

Both vehicle routing and vehicle scheduling are NP-hard. Most existing approaches to the two problems resort to metaheuristics which circumvents the intractability of the problem by applying higher-level strategies guiding the course of lower-level heuristics to go beyond the local optimality (Glover, 1986). Recently, two promising metaheuristic computing frameworks have emerged. (1) Hyper-heuristics (Burke et al., 2013) contemplate an architecture for the reuse of existing domain-dependent heuristics, thus reducing the effort in code development and allowing for automatic creation of compound heuristics. The algorithm design can thus be focused on higher-level heuristics which optimize the strategies for selecting domain-dependent heuristics and accepting the trial solutions. (2) Hybrid-heuristics (Talbi, 2002) hybrid heuristics or metaheuristics with any metaheuristics for obtaining a more effective form of optimization. Many variations of Hybrid-heuristics can be constructed by using different cooperating schemes when executing the involved heuristics or metaheuristics. Moreover, other hybrid approaches look into cooperation between techniques from different domains. The *Simulation-based Optimization* (Figueira and Almada-Lobo, 2014; Nikolopoulou and Ierapetritou, 2012) can handle optimization under uncertainty by taking advantages from the great detail provided by simulation

and the search capability for optimality by optimization technique. The matheuristics (Puchinger and Raidl, 2005; Maniezzo et al., 2010) is a notion of hybridizing mathematical programming and metaheuristics. For example, the metaheuristics can be applied to quickly derive a tighter bound for cutting the solution space to be explored by mathematical programming. The metaheuristics can also decompose the given problem into several sub-problems, each is then solved to optimality by mathematical programming methods.

The above-noted metaheuristics do not stick to a particular metaheuristic algorithm. Instead, an abstract model is defined and it is suited to a broader class of problems. According to the abstract model, an effective algorithm can be quickly constructed or evolved. The integrated problem of vehicle routing and vehicle scheduling is computationally hard and highly constrained, this paper thus develops a cooperative coevolution approach consisting of Hyper-heuristics and Hybrid-heuristics to provide an effective solution. The contribution of this work includes the following. (1) We propose a bi-objective mathematical formulation for the challenging problem considering simultaneously the vehicle routing and vehicle scheduling scenarios which better fit the cross-docking operations in practice. To facilitate green logistics, the vehicle CO_2 emission intensity is regulated. (2) As a response to our bi-objective mathematical formulation, a cooperative coevolution approach consisting of Hyper-heuristics and Hybrid-heuristics is developed for achieving continuous improvement in alternating objectives. The performance gain by using our approach is not obtainable by traditional methods which treat the two sub-problems independently and combine the sub-optimal solutions. (3) The performance of our approach is illustrated with real geographical data and compared with existing models. Based on intensive simulations, we present convergence 95% confidence analysis and worst-case analysis to provide reliable performance guarantee.

The remainder of this paper is organized as follows. Section 2 presents the literature review of warehousing, vehicle routing, vehicle scheduling, and the state-of-the-art metaheuristics. Section 3 proposes the mathematical formulation and the cooperative coevolution approach. Section 4 articulates the experimental results and performance analyses. Finally, Section 5 concludes this work.

2. Literature review

2.1. Warehousing

The operation efficiency of supply chains relies heavily on warehousing technologies, which include receiving, storage,

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