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A branch-and-price approach to evaluate the role of cross-docking operations in consolidated supply chains

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A B S T R A C T

Supply-chain management and optimization aims at reducing costs and inventories. One way to increase the supply-chain efficiency is to use cross-docking for consolidating shipments from different suppliers. Cross-docking is a warehousing strategy used in logistics that consists on moving goods from suppliers to customers through a cross-dock facility. The employment of this strategy must be carefully evaluated because sometimes transportation requests can be better directly moved from source-sites to destination. A realistic problem studying the convenience of direct delivery, avoiding some cross-docking transfers, is here discussed. An efficient methodology for finding (near)optimal solutions is also described. The methodology is based on the use of column generation embedded into an incomplete branch-and-price tree. The approach provides (near)optimal solutions by solving the column generation sub-problems without necessarily considering all unexplored nodes in the search-tree. Finally, we show computational results on numerous test problems and on four configurations of the addressed case study.

1. Introduction

Nowadays, supply chain management and optimization is a critical aspect of modern enterprises and a very active research area (Papageorgiou, 2009). The goal of the supply chain planning and plant scheduling problem consists on determining the optimal manufacturing and network distribution policies for the entire supply chain (SC) of a company in order to fulfill a pre-established economic objective. Indeed from a multisite perspective, this integration problem is even more challenging, since it requires integration across both spatial and temporal scales (Grossmann, 2012). Chemical and industrial companies usually carry out a series of activities such as purchasing raw materials from suppliers, manufacturing and storing end-products at intermediate facilities to later deliver them to final customers. Suppliers, manufacturers, warehouses and customers are the major components of an typical SC carrying goods from the upstream to the downstream side of the SC (Dondo et al., 2011). Supply chain management aims to control in the most efficient way the goods flow through the SC. An usual way to increase the efficiency of the SC is to outsource the movement of shipments on third parts logistics companies (3PL) that operate with a very high efficiency level. Small scale manufacturing companies usually lack resources to develop their own logistics leg and therefore are forced to outsource. In those cases, 3PL companies are required to consolidate shipments from different suppliers. After consolidating and sorting goods according to their destinations, incoming shipments move across the crossdock (CD) to exit doors where they are loaded onto outbound trucks that start their delivery routes. So, 3PL companies usually utilize cross-docking to consolidate shipments in order to efficiently operate the whole system. The logistic operator must coordinate truck loading and unloading operations with inbound and outbound vehicle routes. The more coordinated these issues are, the more cost and time effective the system should be. Nevertheless, it may not be convenient to force the transshipment of all cargo on the CD if the source and destiny locations of some requests are nearly placed. In that case, the orders can be driven directly from the pickup place to the delivery location rather than moving first to the CD platform.

The so called pick-up and delivery problem with cross-docking (PDPCD), first introduced by Santos et al. (2013) deal with the integration of vehicle routing and cross-docking operations, allowing some vehicles to avoid the stop at the CD if this is convenient to reduce transportation costs. The problem simultaneously considers the following logistics subproblems: (i) the pickup vehicle routing problem; (ii) the loads exchange between vehicles on the CD; (iii) the delivery vehicle routing problem; and (iv) the pickup and delivery problem for orders directly driven from the pick-up site to destiny. All subproblems should be coordinated in order to optimize the material flow from suppliers to destination locations. The coordination of pick-up and delivery routes jointly with the use

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Nomenclature

Sets

A arcs of the routes network
I^+ pick-up sites
I^- delivery sites
R^{+-} pick-up and delivery routes
R^+ pick-up routes
R^- delivery routes
Γ transportation requests

Parameters

a_i earliest arrival time at the pick-up/delivery site i
a_{ir} binary parameter denoting that site i is visited by the route r
b_i latest arrival time at the pick-up/delivery site i
cf_v fixed cost of using a vehicle
c_r cost of the route r
$\hat{c}_r^{+-}$ reduced cost for a mixed route
$\hat{c}_r^{+}$ reduced cost for a pick-up route
$\hat{c}_r^{-}$ reduced cost for a delivery route
d_{ij} distance between the locations i and j
l_i, l_j, l_{ij} load to pick-up from the site i and to deliver to the site j
M_C, M_D, M_T upper bounds for the travel cost (C), the traveled distance (D) and the travel time (T)
q transport capacity of vehicles
st_i stop time at the pick-up/delivery site i
t^{max} maximum allowed routing time
$t_{ir}{}^-$ start time of cargo on the cross-dock for the load to deliver to site i
$t_{ir}{}^+$ unload time on the cross-dock for the cargo collected on site i
$\pi_i{}^+$, $\pi_i{}^-$ price associated to the pick-up/delivery site i
$\pi_\tau{}^t$ price associated to the loading/unloading time for request τ

Binary variables

X_r variable denoting that the route r belongs to the optimal subset of feasible routes
S_{ij} variable for sequencing the locations i and j
Y_i variable used to determine that the site i belongs to the route designed by a slave routes-generator problem

Continuous variables

CV total cost of the route designed by a slave routes-generator problem
D_i distance traveled to reach the pick-up/delivery site i
T_i time spent to reach the pick-up/delivery site i
$T_{end}{}^+$ end-time of unload activities on the CD
$T_{start}{}^-$ start-time of load activities on the CD
$T_i{}^+$ end-time for the unload of cargo from site i in the cross-dock
$T_i{}^-$ start-time for delivery of cargo to site i in the cross-dock
TV time spent by the route designed by a slave routes-generator problem

of mixed pick-up and delivery routes may produce a significant improvement on the overall distribution efficiency. In this work, we study, the coordination on the CD of unload and load tasks and the possibility of also using direct delivery trips from a 3PL point

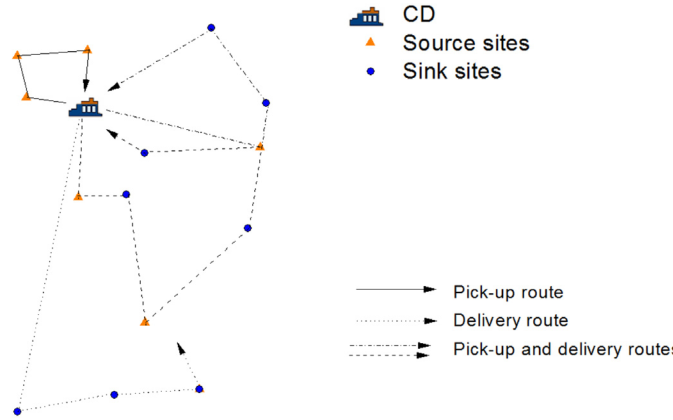

Fig. 1. Illustrating the problem.

of view. The logistic operator is required to consolidate on the CD shipments from different sources to later deliver them to final destinations, taking also into account the possibility of direct delivery of some requests. The problem studied can be viewed as a variation of the PDPCD defined by Santos et al. (2013) that explicitly considers the time coordinating constraints between unload times from inbound vehicles and loading times on outbound vehicles. While the PDPCD considers a fixed fleet with a given number of vehicles, the problem here researched considers the fleet size as a variable derived from the problem solution. Also it considers delivery of stored loads from a source location and reverse logistics transport of some goods back to a depot. The problem is sketched in Fig. 1.

The remain of the paper is organized as follows. In Section 2, we review the literature on issues related to the problem studied. The problem is described and formulated in Section 3. The incomplete branch-and-price methodology devised to solve the problem is detailed in Section 4. Numerical results on examples of the literature and on a case study are presented in Section 5 and the conclusions are outlined in Section 6.

2. Literature review

The need for good and, if possible, optimal solutions for routing problems has motivated, over the past decades, the development of an impressive number of solution algorithms, both exact and heuristics. Reviews on the subject could be found in Bodin et al. (1983), Ball et al. (1995), Desrosiers et al. (1995) and Ahuja et al. (2002). As the computing power increased and the solution techniques evolved, realistic and complex problems have been benefited from such developments. The integration of routing planning with production planning, to tackle sophisticated supply chains, was one of such developments. In this way, the integration of cross-docking with vehicles routing problems naturally arises. Cross-docking has already been applied in the1980s by Wal Mart but it has attracted attention from academia much later and mostly during the recent years (Van Belle et al., 2012). During the last years, a considerable number of papers on the subject have been published (Apte and Viswanathan, 2000) and because of the growing interest from industrial companies, more research on this topic should be expected. At the tactical and operational levels, contributions related to truck scheduling were reviewed by Boysen and Fliedner (2010). Van Belle et al. (2012) reviewed also numerous additional issues related to cross-docking as the physical and operational characteristics of the CD, the location and layouts of the CD, the associated vehicle routing problems and the door-to-vehicle assignment problems. Numerous mixed integer programming models for trucks scheduling problems of small or medium sizes, and meta-heuristic approaches for large-size case