Scheduling and routing problem at a cross-dock warehouse: application of Tabu search

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Abstract: Cross-dock warehouses are widely used for distribution of perishables to minimize the time the products spend in the warehouse. However, operations at cross-dock warehouse require close coordination between scheduling of incoming supplies and outgoing deliveries so as to minimize the total time products spend in the supply chain. The objective of this research is to optimize the cross dock warehouse operations so that the products can be delivered just in time while lowering the total cost of distribution. We focus on the integration of vehicle scheduling and routing, while also incorporating product consolidation and delivery time window constraints. The system is modeled as a mixed- integer program with the objective to minimize the system costs of product delivery. An initial model in CPLEX could only be solved for small sized problems. We are now developing a Tabu search-based algorithm to solve real-life sized problems.

1 Introduction

Cross dock is a commonly used warehousing strategy to deliver products with short-shelf life. A traditional warehouse performs four main activities: receiving, storing, picking, and shipping; the cross dock eliminates the storing and picking activities, which are the two most expensive (and time-consuming) activities [1]. Implementing a cross docking warehouse for perishable product distribution expedites the product distribution, shortens the delivery cycle time, and improves customer satisfaction [2] [3]. Cross-docking also enables consolidation of orders and delivery in Full Truck Load (FTL) rather than Less Than Truck Load (LTL), thereby reducing the transportation cost. Thus, compared with a traditional warehouse a key advantage of cross docking is cost savings, in terms of storage costs, inventory cost, transportation cost, and labor costs [2] [3]. Many companies have successfully implemented cross-docking centers, such as WalMart, JCPenney and Supervalu [4].

At most cross-docking centers, the vehicle scheduling and planning of vehicle routes is done in sequence, and in isolation. The vehicles are scheduled on a First Come First Served basis; this policy has some disadvantages, such as large number of early and tardy jobs and long waiting times [5]. Transportation management systems are used for planning of vehicle routes for deliveries. Product must also be consolidated before delivery to enable deliveries in FTL and minimize transportation costs. Delivery time windows must also be honored to avoid any tardy and early deliveries, especially for perishable products.

Thus in this research we optimize jointly the schedule of vehicles and their delivery route, taking into account product consolidation and delivery time windows. The cross docking warehouse layout for perishable products is shown in Figure 1.

The outline of the paper is as follows: section 2 presents the literature review of scheduling and routing at cross dock warehouses. Section 3 discusses the cross dock model for perishable distribution and results of our early experiments. Section 4 presents the flow chart for a new tabu-based search algorithm we are developing to solve the original model. Finally, Section 5 provides the conclusion and future research direction.

2 Literature Review

The operational planning of cross dock warehouses covers scheduling, assignment, transshipment, vehicle routing, and product allocation problems [6]. Existing studies of cross-docks have mainly focused on minimizing the make-span or operation time; [7] proposed a vehicle scheduling model to minimize the operation time in the cross dock which includes temporary storage area. [8] propose a scheduling model to minimize the earliness and tardiness penalty cost of containers processed at the cross dock. They propose a model to schedule the break-down and build-up processes for incoming and outgoing containers; their model minimizes the earliness and tardiness of the containers, incorporating due date and time window constraints.

[9] propose a model to determine the pick-up and delivery routing of vehicles, along with the product consolidation decision, while [10] consider time windows and assume there is no need to consider simultaneous arrival of inbound vehicles.

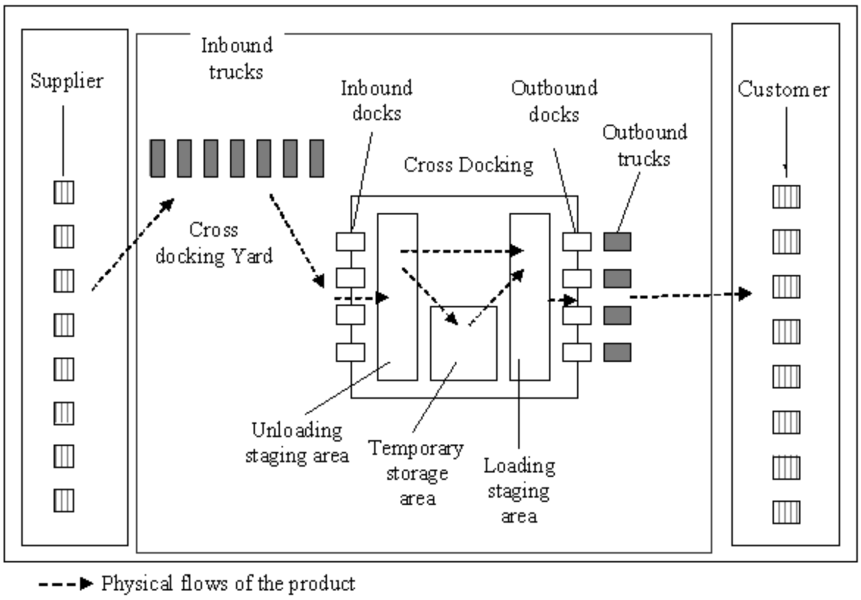

Figure 1: Cross dock warehouse for perishable products

Even though numerous studies have looked at scheduling in cross dock facilities, to the best of our knowledge, no study has looked at vehicle routing and vehicle scheduling at cross-docking center jointly. These decisions can affect one another. Determination of inbound vehicle arrival and release time determines the availability of the product in the cross-docking warehouse. Also the determination of the outbound vehicle routing (including its departure time from cross-docking center and the completion time of delivery to the customer location) is dependent on the availability of the product in the cross dock. While a sequential determination of vehicle schedule and vehicle route may lead to a (local) solution, we believe only a joint determination of the two would lead to a globally optimum solution. This research focuses specifically on joint optimization of scheduling and vehicle routing at a cross-docking center, considering the customer delivery time windows and product consolidation for distribution of perishables.

3. Vehicle routing and scheduling model (VRSP) of cross docking warehouse

3.1 Problem description

The process flow at the cross docking center is described next. The inbound vehicle arrives at the cross dock facility, is released to an inbound dock door, is processed in the inbound area and unloaded. After unloading, the order can be sent directly to the outbound area for loading process or stored in the intermediate storage area while the orders are waiting to be loaded. These choices are determined by the decision of the release time and departure time. Release time is the time at which inbound vehicle and orders are unloaded at the cross dock.

Then based on the departure time and consolidation decisions, the orders are loaded onto the outbound vehicle for delivery. Departure time is the completion time of loading the order onto the vehicle, and is also the time at which the outbound vehicle and orders depart from cross dock for delivery of the order.

In this system, there are two key decisions to be made. The first decision is related to handling inbound shipments: the operations and schedule at the cross dock yard and inbound area, while the second decision is related to the outbound-side of the facility: operations and schedule of the outbound area up to the customer location. At the cross dock incoming yard, the manager determines the schedule for inbound vehicle arrival time to cross docking center. At the inbound area, when the inbound vehicle arrives and is parked at the cross docking yard, the cross dock manager specifies

(1) the release time of inbound vehicles,
(2) sequence of inbound vehicles, and
(3) assignment of inbound vehicle to an inbound dock door.

After the products are unloaded, the decisions related to outbound area need to be made, which are:

(1) product consolidation for outbound vehicle;

(2) scheduling of outbound vehicles, that consists of departure time of outbound vehicles, sequence of outbound vehicles, and assignment of outbound vehicles to outbound dock door, and

(3) routing of outbound vehicle.

Once these decisions are made, product earliness, tardiness, inventory holding, and outbound transportation costs can be computed.

3.2 Model development and formulation

The proposed model (VRSP) in this research is motivated by the scheduling model [8] and vehicle routing model [9] and also incorporates product consolidation and delivery time window considerations.

In the VRSP model, the products are consolidated and then loaded onto the outbound vehicle. After all the consolidated orders have been loaded, the vehicle departs from cross dock to deliver the products to different customer locations, finally returning to the cross docking center. There is a temporary storage area in the cross docking center where unloaded orders, which are yet to be consolidated, are stored. The objective of the model is to determine the schedule for inbound vehicle (its arrival and release time), outbound vehicle departure time, and the route of delivery so as to fulfill the customer delivery time window requirements and minimize the total cost of delivery.

The development of the model relies on the following assumptions:

1) Cross dock yard space is unlimited.
2) Every inbound and outbound dock door is used for unloading and loading (no empty inbound and outbound dock doors).
3) Temporary storage area is unlimited.
4) Outbound vehicles can deliver multiple products to multiple customer locations.
5) All inbound and outbound vehicles have same, fixed capacity.
6) All outbound vehicles are available at the beginning of the planning horizon.
7) Travel times are assumed constant, ignoring traffic jams.

For notation and formulation of the model, the reader is referred to [11]. The proposed VRSP model is solved using the CPLEX solver for a range of variables. Based on the computational result of the VRSP model, in case of 2 vehicles and 2 dock doors, the model can be solved in a reasonable time. However, the computation time increases exponentially as the problem goes from being small to medium scale. The experiments show that CPLEX solver can solve the VRSP in a reasonable and acceptable time only for small scale problems. For large-scale, real-life problems, the time taken is very long and impractical.

4. Tabu-based Search Algorithm for VRSP (TSA-VRSP)

TSA-VRSP is a heuristics algorithm developed to solve Vehicle Routing and Scheduling Problem at the cross-dock warehouse. Since VRSP is an NP hard problem and is not solvable for life-size systems, we propose TSA-VRSP to solve the problem with dozens of dock-doors and hundreds of orders. TSA-VRSP is a heuristics algorithm based on Tabu Search (TS) method. It uses TS to generate neighborhood solutions. After that, each neighborhood (candidate of best solution) is examined by calculating its total cost. The best solution for VRSP is solution that has the lowest total cost.

TSA-VRSP schedules backward by starting from customer side, to outbound side of cross dock, to inbound side of cross dock, finally ending at supplier side. It starts by determining the outbound truck routing (Z), then determines the outbound truck schedule that consists of outbound truck sequence (X) and assignment (Y) at outbound dock door, outbound truck departure time (DT), outbound truck arrival time to the customer location (S), and earliness (E) and tardiness (T). After that TSA-VRSP continues to determine the inbound truck schedule that consists of inbound truck sequence (x) and assignment (y) at inbound dock door, inbound truck release time (RT) and arrival time (AT). Based on those decision variables, the total cost (transportation cost + earliness cost + tardiness cost + inventory cost) can be determined.

The notation used in the TSAVRSP flowchart is as follows:

- M : a large number.

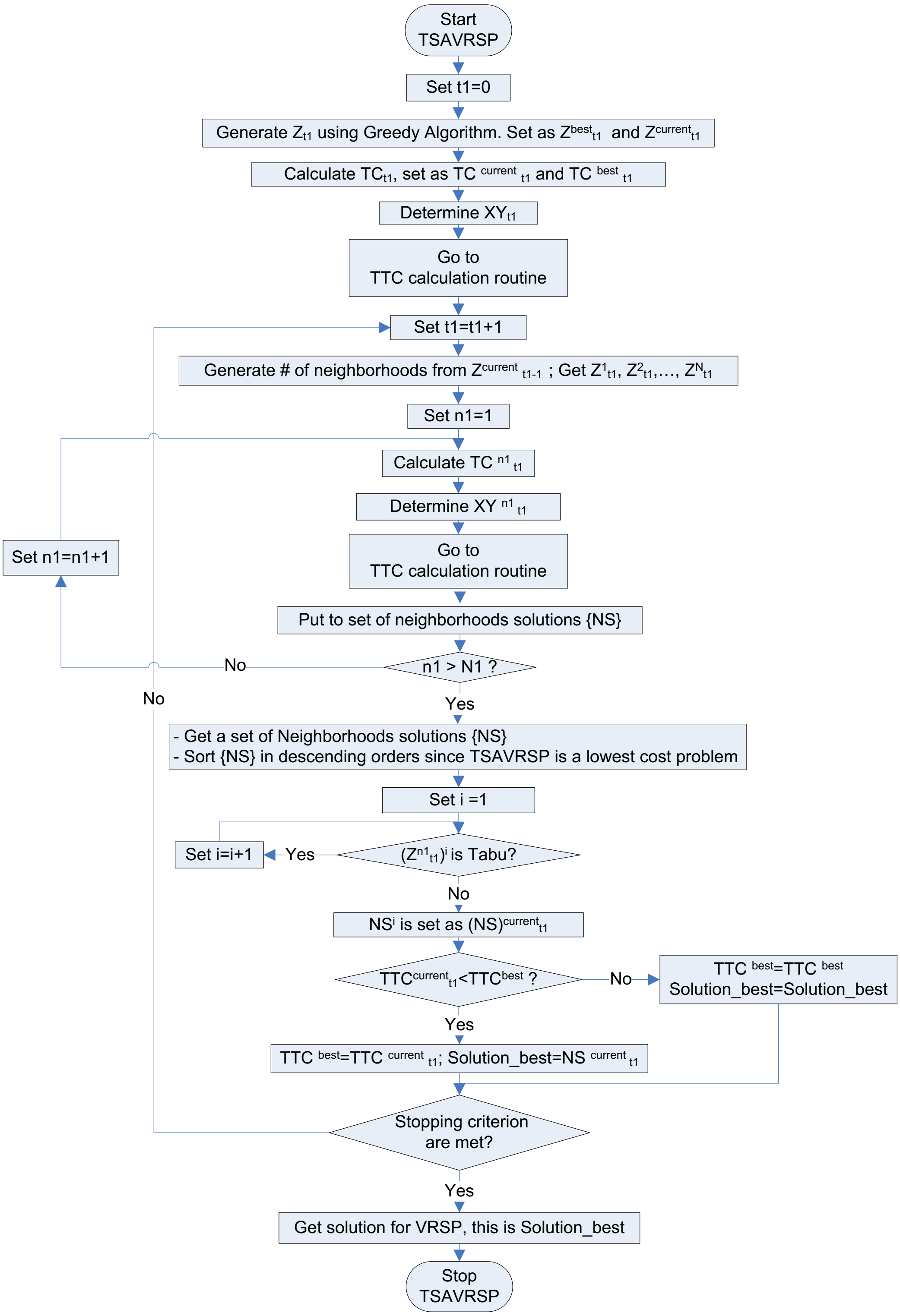

Figure 2: Flow-chart of TSA-VRSP

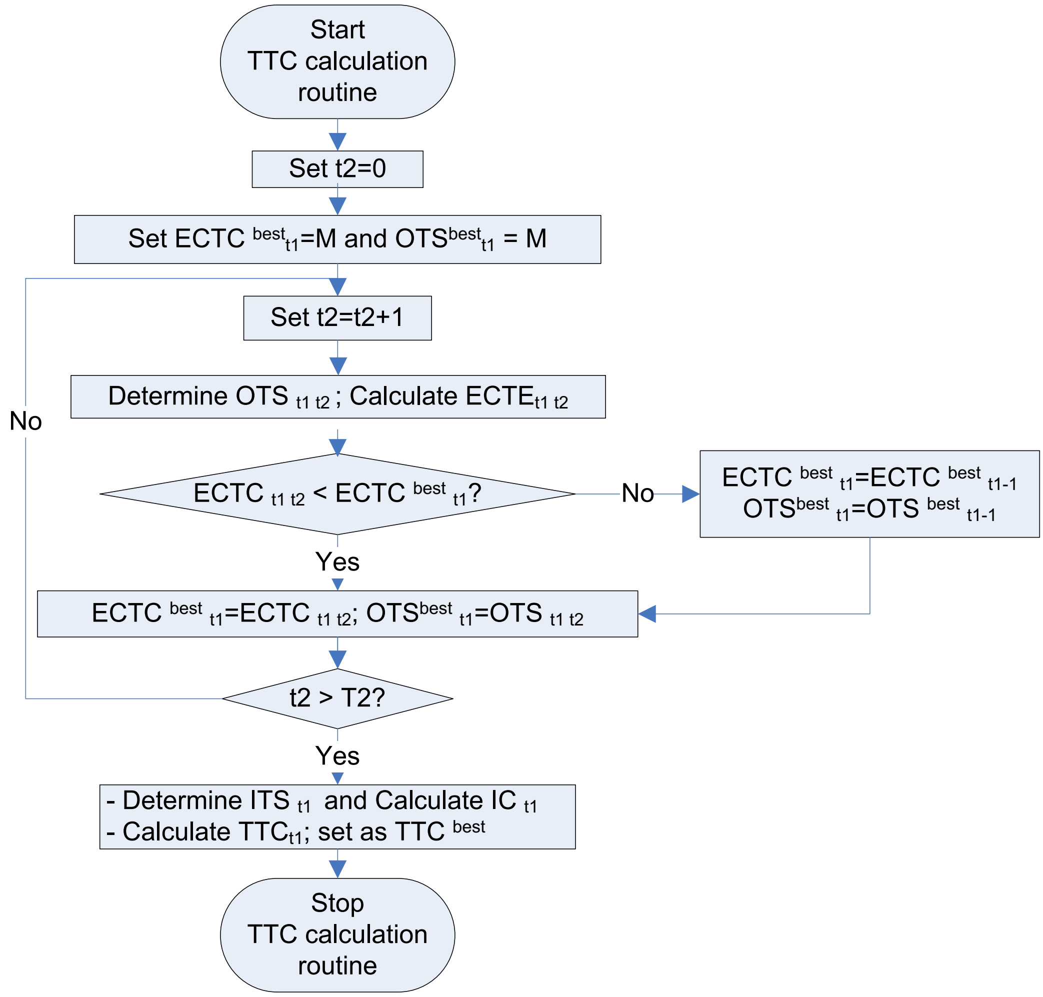

Figure 3: TTC Calculation Routine

- Z : outbound truck routing.
- XY : outbound truck sequence and assignment at outbound dock door.
- OTS : a set of decision variables for outbound truck schedule, consisting of outbound truck departure time (DT), arrival time to customer location (S), earliness (E), and tardiness (T). (XY and OTS form the outbound truck schedule).
- ITS : inbound truck schedule, consisting of sequence and assignment of inbound truck to inbound dock door (x and y), release time (RT), and arrival time (AT).
- TC : transportation cost.
- ECTC : earliness cost and tardiness cost.
- IC : inventory cost.
- TTC : total cost (= TC+ECTC+IC)
- t1 : iteration number for decision variable Z
- t2 : iteration number for decision variable OTS
- n1 : number of neighbourhoods. The neighbourhoods are generated using TS neighbourhood generation method: adjacent pairwise interchange, last insertion, all pairwise interchanges, or all insertions.

TSA-VRSP flowchart is depicted below in two parts. First part (Figure 2) is the main algorithm (named as TSA-VRSP), while the second part depicts a function called TTC calculation routine (Figure 3). The routine determines (for each set of parameters) the outbound truck and inbound truck schedule, along with its total cost (TTC).

TTC routine determines:

1. Outbound truck schedule consisting of: departure time, arrival time to customer location, earliness and tardiness;
2. Earliness cost and tardiness cost;
3. Inbound truck schedule that consists of: sequence and assignment of inbound truck to dock door, release time, and arrival time to cross dock;
4. Inventory cost, which is a function of departure time and release time;
5. Total cost, which is a function of transportation cost, earliness and tardiness cost, and inventory cost.

5. Summary and future work

Cross docking is considered the best strategy for distribution of short-shelf products that require quick turn-around and delivery to customer locations.
This research considers the integrated routing and scheduling problem for distribution at a cross dock warehouse. The proposed model also considers delivery time windows since the product is perishable. Product consolidation is also considered in the proposed model as it ensures FTL deliveries and minimizes transportation cost.
The VRSP problem is formulated as a Mixed Integer Linear Program (MILP) with the objective of minimizing the earliness, tardiness, inventory holding, and transportation costs. As the resulting model can only be solved for small size problems in a reasonable time. We then propose a Tabu-search based algorithm to solve real-life sized problems in a reasonable amount of time, which is the primary objective of this research. The work is ongoing, and the initial results look promising.

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