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APPLICATION OF TABU SEARCH TO SCHEDULING TRUCKS IN MULTIPLE DOORS CROSS-DOCKING SYSTEMS

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RÉSUMÉ

Cette recherche focus sur l’amélioration des cross-dockings en vue d’augmenter les niveaux de performance du service et de réduire les coûts. L’algorithme de la recherche avec tabous est étudié pour trouver la séquence optimale d’entrée et sortie des remorques au cross-docking. L’objectif de cette recherche est de maximiser le nombre total de transferts directs entre le fournisseur et une destination finale commune de livraison.

Dans les stratégies de distribution actuelles, l’objectif est de synchroniser les chaines du fabricant et du client. Le cross-docking implique de recevoir les produits d’un fournisseur pour plusieurs clients et d’occasionnellement consolider cela avec les produits d’autres fournisseurs pour des destinations finales de livraison communes.

En résumé, l’approche examinée dans cette recherche donne une occasion significative pour l’amélioration des opérations au Cross-docking par la réduction du stockage des produits.

ABSTRACT

Today's supply chain management performance has been affected by continuously increasing pressure of market forces. The pressure of market includes demands on increased flow of products and throughput with less amount of storage, also customers demand for more products with lower operational costs and more value-added services provided to customers. Supply chain is responsible in cost reduction and service levels increase by providing transshipments across its members. However supply chain has to face fluctuations of demands with the short available lead times. Physical problem of warehouse limitations and also inventory costs and shipping affect the performance of supply chain. In today's distribution strategies, the main goal is to provide a synchronization of customer chains and the suppliers. The objective is to reduce the inventory buffering between customers and suppliers. The idea of cross-docking is to receive different goods from a manufacturer for several end destinations and possibly consolidate the goods with other manufacturer's items for common final customers; then ship them in the earliest possible time.

The focus of this research effort is to improve cross-dock operations with the goal of increasing the service performance levels and reducing costs. Specifically, metaheuristics algorithm of Tabu search is investigated for finding optimal sequence of incoming and outgoing trailers at cross-docks. This thesis reviews available research literature on cross-dock operations. Tabu search for the truck scheduling problem is presented along with results.

Tabu search algorithm is investigated for the truck scheduling problem in the multiple doors cross-docking with unknown incoming and outgoing sequences. The objective of this research is to maximize the total direct transfer of products from a supplier to common final delivery destinations**.** The algorithm is implemented in C++ and analyzed using different problem instances. The results gained from algorithm of Tabu search are compared with other iterative heuristic descent method. The results indicate that the Tabu search performs significantly better than the descent method for large problem instances. In general, the results present that a metaheuristic algorithm of Tabu search for multiple or single door cross-docking offers the largest potential for improvement. In summary, the approach explored in this research offers significant opportunity to improve cross-dock operations through reducing storage of products.

CONDENSÉ EN FRANÇAIS

Les forces actuelles du marché accroissent continuellement la pression sur la performance de la gestion de la chaîne logistique, avec des demandes d'augmentation du flux de produits et du débit tout en réduisant les stocks, aussi la demande des clients tend vers plus de diversité de produits avec des coûts d'exploitation plus bas et vers plus de services à valeur ajoutée fournis aux clients. Le défi majeur pour que l'offre réponde à la demande est de coordonner le transbordement à travers la chaîne d'approvisionnement pour réduire les coûts et augmenter les niveaux de service face aux fluctuations de la demande, aux temps de délais courts, aux limitations d'entrepôts, aux coûts de livraison et d'inventaire. Cependant dans les stratégies de distribution actuelles, l'objectif est de synchroniser les chaines du fabricant et du client. Le but est que le cross-docking remplace le stock tampon comme un mécanisme liant. Le cross-docking implique de recevoir les produits d'un fournisseur pour plusieurs clients et d'occasionnellement consolider cela avec les produits d'autres fournisseurs pour des destinations finales de livraison communes ; puis livrer à la première occasion.

L'effort de cette recherche a été concentré sur l'amélioration des cross-dockings en vue d'augmenter les niveaux de performance du service et de réduire les coûts. Plus spécifiquement, l'algorithme métaheuristique de la recherche avec tabous est étudiée pour trouver la séquence optimale d'entrée et sortie des remorques au cross-docking. Cette thèse présente une revue de littérature sur les travaux de recherche disponibles sur les opérations de Cross-docking. Une approche de la solution au problème de planification des camions est présentée avec des résultats.

L'algorithme de la recherche avec tabous à été étudié pour le problème de planification des camions à un Cross-docking à portes multiples avec des séquences d'entrée et sortie inconnues. L'objectif de cette recherche est de maximiser le nombre total de transferts directs entre le fournisseur et une destination finale commune de livraison. L'algorithme a été implémenté en langage C++ et analysé en utilisant différents cas. Les résultats de la recherche avec tabous ont été comparés avec une autre méthode de descente itérative heuristique. Les résultats indiquent que la recherche avec tabous est plus efficace que la méthode de descente pour un nombre important de cas. De manière générale, les résultats montrent que l'algorithme métaheuristique

de la recherche avec tabous pour les cross-dockings à une porte ou à portes multiples offre un potentiel d'amélioration plus important. En résumé, l'approche examinée dans cette recherche donne une occasion significative pour l'amélioration des opérations au Cross-docking par la réduction du stockage des produits.

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CHAPTER 1: INTRODUCTION OF PROBLEM

1.1 Role of Supply chain logistics

Logistics plays an important role in the distribution due to high volume of orders and customer's demands. Customers expect for receiving their orders faster with higher quality and lower cost. Supply chain tends to operate in a cost-efficient frame such that maximizing the customer satisfaction while minimizing total costs. The total cost includes supply, production, logistic and tardiness costs. Supply chain management performance is under pressure of today's market effects. Demands on flow of products are increased and it is needed to have less amount of inventory; the demanded products are supposed to be serviced in lower operations costs with better qualities.

According to the paper of (Waters 2010), the operation of moving products inwards is named upstream activities and those that move products outwards are named downstream activities. Each organization also divides its customers into different levels of tiers. Customers that buy their ordered items directly from the suppliers and those get their orders from previous group of customers and so on to final customers.

A supply chain includes chains of activities and organisation's members that goods move through from manufacturers to final customers. The most challenging part of a supply chain is that all the materials from suppliers are available and ready to deliver them to customers. Different types of decisions are discussed for the concept of supply chain. Design and the shape of the chains that include the location of facilities and also number of facilities and type of operations could be decided for each supply chains. On the other hand, some decisions are likely to concern the moving of materials through the chain(Waters 2010).

1.2 Distribution center

In addition to better services, mostly customers expect receiving their orders in a short period of time. While, providing direct long-distance shipping of orders is difficult due to far distance between customers and suppliers. Therefore, it should be a connection center between manufacturers and customers. This center operates as a distribution center that serves as a warehouse for a variety of products. A distribution center is part of a logistics chain. Trucks delivering and picking up products from warehouses and transportation of items are included in this logistics chain. The manufacturer ship items to the distribution center which then stores the items. When these stored items are ordered, they will ship the required items from distribution center to the retailers. Two methods of distribution exits; Firstly, manufacturer ships the products directly to the retails or secondly, products arrived to distribution centers and then products are shipped to different customers.

1.3 Traditional logistic and the need for Cross-docking

Traditional logistic comprised of receiving products from upstream stage, storing in warehouse stage and shipping to the customers. This configuration incurs high expenses to supply chain due to costs associated with storage and inefficiency in transportation system. Nowadays, a new approach called cross-docking applied to supply chain to optimize the traditional costly configuration. Kinnear (Kinnear 1997) present cross-docking system as a transshipment platform in supply chain where the products are received from upstream stages and arranged for final destinations based on customers' orders. Cross-docking has preference, compared to traditional transportation since it minimizes the storage (from several weeks or days to less than 24 hours) as well as maximizing efficient transportations. Distribution center in traditional way, receive products from suppliers and then store them in an inventory; when the products inside the storage are raised for an order, then the distribution center ship them to the final retailers (Kulwiec 2004) (See Figure1-1).

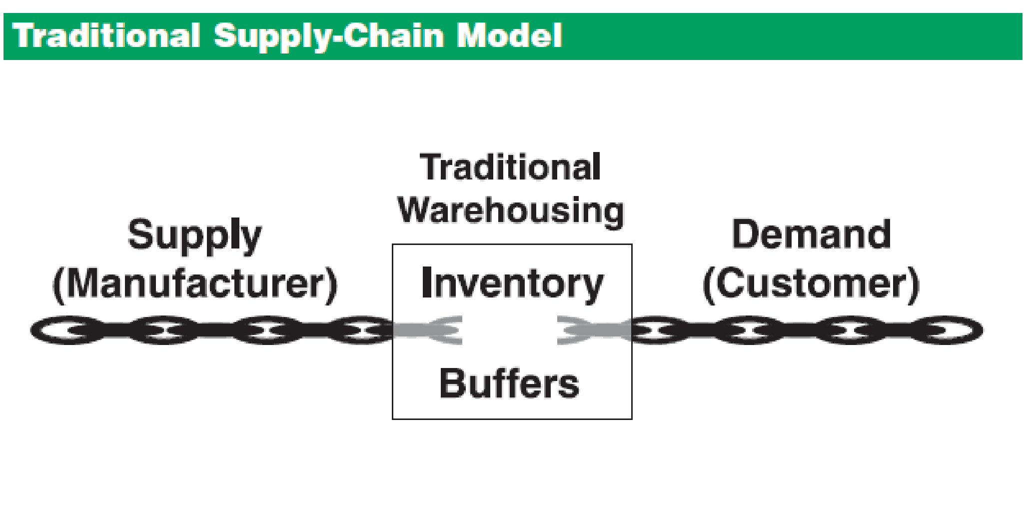

Figure 1-1- Supply chain management model – Traditional warehousing; Source: (Kulwiec 2004)

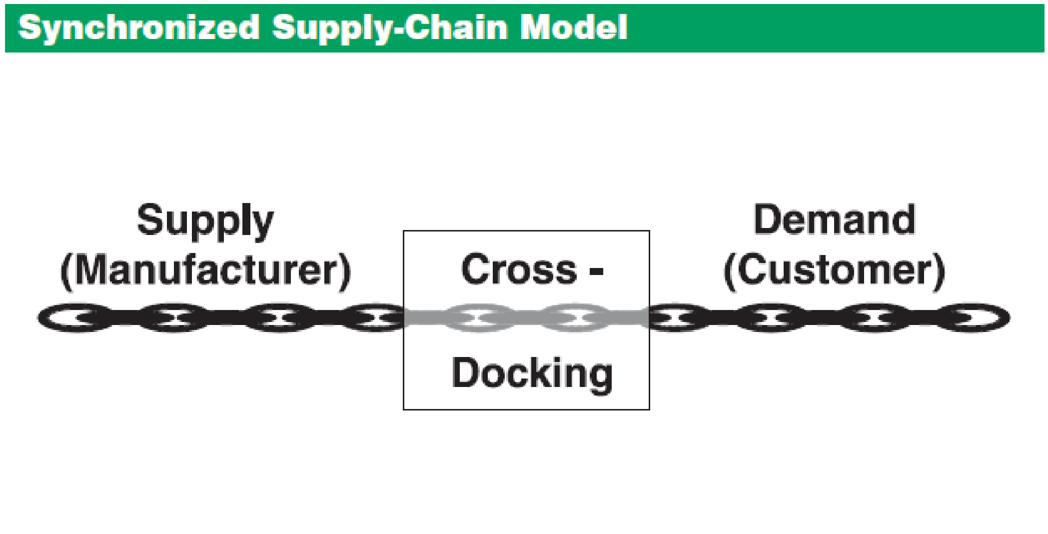

Figure 1-2 - Supply chain management model – Cross-docking; Source: (Kulwiec 2004)

However in today's distribution strategies, the objective is to synchronize the manufacturer and customer chains (Figure 1-2) (Kulwiec 2004). A supply chain using the cross-dock is able to speed p shipment from manufacturers to final destinations quickly and cost-effectively. It is essential to select and design the appropriate type of cross-dock with suitable strategies.

Each cross-docking optimization requires high qualified operation between on all members of its supply chain. Sharing information with effective processes and high reliability are key roles for each successful cross-docking (Vogt 2010). In different types of supply chains, cross-docking is applied.

Cross-docking terminal is a distribution center carrying a considerably reduced amount of storage. Cross-docking, is the way of handling product that involves loading and unloading goods from an incoming truck onto an outgoing truck.

In today's supply chain, with the focus on customer satisfaction, shipping strategies are changing rapidly. A supply chain is the combination of activities and strategies that the companies use to move a freight from manufacturer to end customer. The increase in customer demand, companies are constantly searching for cost effective distribution methods to reduce product cycle time.

Cross-docking is applied in distribution strategies to achieve the goals. In each warehousing, there are four major functions of receiving products, store them, order picking and finally ship them. Inventory and order picking are two of costly functions among them. Costs of inventory holding and labor operations are significantly noticeable. Cross-docking is one of the approaches in supply chain that eliminate these two expensive operations of storage and order picking (Bartholdi and Gue 2004; Li, Lim and Rodrigues 2004; Van Belle, Valckenaers and Cattrysse 2012).

1.4 Introduction to Cross-docking system

Cross-docking consists of receiving goods from a manufacturer for different final destinations. Cross-docking consolidates these freights with other manufacturer's freights for common customers (Shakeri 2008). This consolidation significantly decreases the transportation costs in supply chain. Therefore, cross-docking transfer products with inbound and outgoing trailers; the main idea is to transfer these goods without items entering the inventory of warehouse. Thus the freights cross the docks from the inbound dock to the outbound dock area (Kulwiec 2004) . According to the paper of (Kinnear 1997), the term of cross-docking has a railway and maritime background. As we noted, this supply chain management concept aims at reduction in inventory costs by divergent freights to outgoing trucks without requiring long-term storage inside the warehouse.

By deleting inventory space inside warehouse, we reduce some major costs of functions of warehousing. Receiving freights, sorting them according to their final destinations, storing, retrieving and shipping them to the retailers are of major functions inside a common distribution center. As mentioned before, storage (due to wide space demanded) and inventory holding costs are costly operations. Labor cost in order picking increase the costs of operations. Cross-docking eliminates the order picking function of a warehouse. The idea is to directly transferring of items from receiving to shipping trailers without storage in between. If any items is demanded to be kept inside the warehouse, the short period of time which is usually less than twenty-four hours is considered. In a cross-docking organizations sometimes this period is less than an hour.

By applying the technique of cross-docking, costs such as penalties for delayed delivery, inventory management and also consideration of a wide space inside warehouse for inventory can be considerably reduced. So, whenever an incoming truck arrives at the yard of a cross-dock, it is assigned to an available strip door, where workers unload the items, sort, categorize and scan to determine their intended destination; then these products are loaded into outgoing trucks and leave the stack or shipping dock for delivery to the retailers.

Significant inventory savings is provided by application of cross-docking; therefore, some operations such as routing to the inventory areas , subsequent detection from inventory and again rerouting back to dock doors is eliminated (Kulwiec 2004).

1.5 Advantages and disadvantages of using Cross-docking

Cross-docking like other modern techniques, provide advantages and disadvantages for the supply chain management. Organization that is planning to use a cross-docking evaluates this process and then decide whether application of cross-docking to their organization in beneficial. Many companies are motivated to use the logistic of cross-docking according to its benefits; a cross-docking Trends report sponsored by Saddle Creek Corporation(Creek 2011) study the benefits of cross-docking. In the study survey respondents reporting that improving service levels and reducing transportation costs are major benefits of applying cross-docking.

In the literature, several advantages of application of cross-docking are mentioned (Boysen N. and Fliedner 2009; Creek 2011; Van Belle, Valckenaers et al. 2012).

Some advantages in comparison with traditional distribution centers are:

- Reduction in costs; these costs include warehousing costs, handling and labor costs;
- Reduction in delivery time from manufacturer to customers;
- Increase in customer service quality;
- Reduction in physical space of inventory and storage;
- Reduction in loss and damage of orders.

These advantages make the technique of cross-docking a famous logistic strategy which is receiving high amount of attention in supply chain management. Therefore, it is essential to pay more management attention to make cross-docking more effective.

Cross-docking is effective for a high volume of product. Although implementation of cross-docking seems easy, but if the demanded requirements of cross-docking are not considered very well, then the cross-docking does not operate properly. Application of cross-docking needs exact information about the shipping route of products and the sequences of trucks. It is essential to have a synchronized supply and demand chain.

“The efficiency of cross-dock could be measured by (a) freight turn time, in traditional warehouses products may stay in a warehouse for a month or more before shipping; in cross-docking products may go out within a day; this logistic significantly increase the turn frequency. (b) Order date to delivery date. Cross-docking may save a day or two off delivery times when compares with less-than-truckload shipments, allowing the right mix of products to reach the customer faster and more efficiently” (DelBovo 2011).

There are many barriers to effective cross-docking. According to the report of (Creek 2011) , in this report, unpredictable demands of products and IT system are two key barriers to the effectiveness of cross-docking. There are other factors that could challenge the effectiveness: Reliability of manufacturers, carriers and lack of materials could also affect the cross-docking.
To handle these problems, it is essential to consider different cross-docking options. For instance, if organisation has the problem of balancing the supply and demand, it might be better to place orders further downstream and picking product at the cross-dock (Creek 2011).
Also to solve the transportation issues, it is helpful to reduce the distance the freights travels after they have been cross-docked. This strategy could help with reduction of freights and shipping costs (Creek 2011).

1.6 Cross-docking structure

Most of distribution centers contain three main parts of receiving (inbound) dock, the storage and the (outgoing) shipping dock. A cross-dock has multiple loading and unloading docks. Strip doors, where full trucks are available to be unloaded, and stack doors, where empty shipping trucks are ready to ship freights for final destinations. Incoming truck from suppliers loaded by stock units (products, pallets or boxes) arrives at the platform and is assigned to the receiving doors (or strip door). Incoming trailers from suppliers are available at receiving doors regardless of their origin and contents. Incoming trailers may be assigned to an empty strip doors directly; or, if none is unoccupied, they may wait in a yard in a queue (Bartholdi John J. and Gue Kevin 2000).

The products are unloaded from trailer and it leaves the platform when all its products are fully unloaded. The unloaded products are sorted and distinguished by their final destination. Then the products are moved to their appropriate receiving door (strip door) where the shipping trucks are available to deliver them to the customers. They are transferred to a shipping platform directly if the shipping truck related to that final destination is available at the shipping dock; otherwise, they are transferred to the temporary storage. After an incoming truck has been completely stripped, it is replaced with another receiving truck waiting in the queue. Also, after the shipping trucks has been filled with its products, it is replaced with an empty truck to be filled (Bartholdi John J. and Gue Kevin 2000).

In Figure 1-3, we present a single door cross-docking system. Cross-docking's structure contains inbound door where the incoming trucks unloaded, temporary storage area (waiting time less than 24 hours) and outbound door where the outgoings trucks loaded.

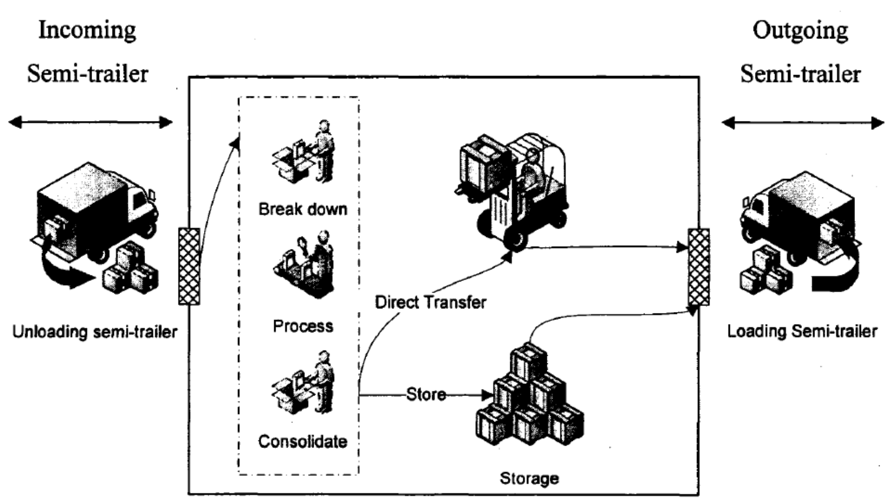

Figure 1-3- "A single door cross-docking system" , Source: (Maknoon 2007)

As it is shown in Figure 1-3, two types of product flow in cross-docking is available; direct transfer from inbound door to outbound door and indirect transfer from inbound door to temporary storage area (in order to wait for future shipment to their final destinations) and from storage area to outbound door. The storage acquisition in indirect transfer increases the inventory costs as well as transportation activities which lead to extra costs. At strip door, the incoming flights from different suppliers are unloaded, processed and ready to send to stack door. The incoming products differ according to their sending destinations and consumers.

Figure 1-4, present the material handling operations inside the cross-dock. The layout of this cross-dock is I-shaped and it has 10 dock doors.

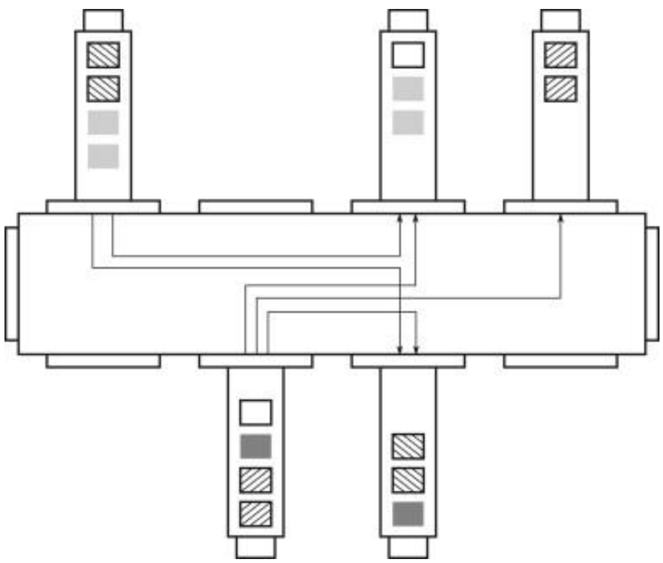

Figure 1-4-Material handling at a typical cross-dock. Source :(Van Belle, Valckenaers et al.)

Facility, operational conditions and strategies inside cross-docking, provide different scenarios and models. Number of available docks inside the site, pattern of organizing the trucks and also the availability of storage inside warehouse provides variety of characteristics for cross-docking. According to the paper of (Boysen N. and Fliedner 2009), the characteristics can be divided into three groups: physical, operational and flow of goods characteristics.

1.7 Cross-docking Characteristics

1.7.1 Physical characteristics

The physical characteristic of cross-docking is supposed to be fixed for a rather long time. Shape of cross-dock, number of dock doors and also internal transportation are considered as the physical characteristics of cross-docking. According to(Bartholdi John J. and Kevin 2004), cross-docking can have variety of shapes; different alphabetic shapes such as I, L, or T are most common. However other shapes of a U, H, or E may be found.

1.7.1.1 Shape of cross-dock

Bartholdi and Gue(Bartholdi John J. and Kevin 2004) study that with respect to labor costs,
Shapes of layout could vary according to the size of cross-docks. Narrow rectangle shape which is able to get maximum use of central doors is suggested for small or mid-sized cross-docks. Also for larger docks, more alternative shapes are suggested. The t-shape and X-shape is among the popular layouts.

1.7.1.2 Number of dock doors

Total number of dock doors is the most important decision about a cross-dock. Shipping doors may be determined by the number of final destinations that the cross-dock must serve. In the literature, some authors limit their studies to only one or two doors. Although it is not realistic, but it could provide a basic cross-docking and a simplified model to study (Van Belle, Valckenaers et al. 2012).

1.7.1.3 Internal transportation

There are two types of internal transportation in the cross-dock. The transportation can be executed manually by workers with forklifts or it can be an automatically carried with a network of conveyor belts. The type of products inside the cross-dock determines the infrastructure of transportation(Van Belle, Valckenaers et al. 2012).

1.7.2 Operational characteristics

The operational decisions can influence the functionality of cross-dock. According to the classification of Boysen and Fliedner(Boysen N. and Fliedner 2009), some operational constraints can be discussed as follow:

1.7.2.1 Door environment - Service mode

The service mode of in a cross- docking terminal influences the degrees of freedom in assigning receiving and shipping trailers to dock doors. In the exclusive service mode each dock door is either exclusively dedicated to receiving or shipping operations. Normally, in the terminals, one side of doors is assigned as inbound and the other side to shipping operations (Boysen N. and Fliedner 2010). Another mode is mixed mode; in this mode, an intermixed sequence of receiving and shipping trailers to be processed per dock door can be allowed.

1.7.2.2 Preemption

In the concept of preemption, we discuss the interruption of trucks during their loading or unload process. It means that whether it is allowed a half-full truck to be removed from the dock and replaced with another one (Boysen N. and Fliedner 2009).

1.7.3 Flow characteristics

The following characteristics are distinguished for the flow of products inside the cross-dock:

1.7.3.1 Arrival pattern

It is the concept of availability of trucks; it is decided whether the trucks are already waiting in the queue on the yard, thus readily available for their operation or they are not ready at time zero and the manager have to wait for their start time and arrival time (Boysen N. and Fliedner 2009).

1.7.3.2 Processing time

This time is related to the whole time of a truck take to (un-)load its freights. In some literature, it is considered that all the trucks have the same processing time. In this type of trailers, the products are same sized (Boysen N. and Fliedner 2009).

1.7.3.3 Deadlines

It is the concept of restricting the departure time of shipping or recieving trailers. It may be decided to allow a shipping truck to depart the platform before a certain time; in a similar way, it is possible that inbound trailers are restricted to be unloaded before a certain moment (Boysen N. and Fliedner 2009; Van Belle, Valckenaers et al. 2012).

1.7.3.4 Intermediate storage

Although cross-docking's goal is to minimize the storage, the minimum amount of inventory inside the warehouse if often inevitable (Boysen N. and Fliedner 2009; Nils 2010).

1.7.3.5 Assignment restrictions

This characteristic is related to the degree of freedom in assigning the trailers to the doors. If there is no restriction, any unoccupied dock door may be assigned to the trailer processing (Boysen N. and Fliedner 2010).

1.7.3.6 Transshipment time

It is introduced as the time between the receiving of products inside the terminal after unloading until their loading time to the shipping trailers (Shakeri 2008). In some literatures, this time is given constant to reduce the complexity of problem (Boysen N. and Fliedner 2009; Nils 2010).

1.7.3.7 Outbound organization

This concept introduced as strategy of allowing the shipping trailer leave the platform when its predefined set of freight is loaded; or it departs at a certain moment (Boysen N. and Fliedner 2009).

1.7.3.8 Product interchangeability

It is introduced as repacking the products inside the terminal (Boysen N. and Fliedner 2009).

1.8 Description of Research Strategy for Addressing Problem

The truck scheduling problem is addressed through the following activities:

- Review literature related to problem and/or proposed solution approach;
- Description of our cross-docking problem, overview and problem statement
- Description of our cross-docking operational characteristic
- Develop solution approaches with Tabu search algorithm for truck scheduling;
- Description of objective function as an approach for estimating direct transfer of products;
- Implement solution approaches in C++ on a personal computing workstation;
- Test and evaluate solution approaches;
- Compare results of solution approaches with existing heuristic approaches

- Summarize findings and make recommendations for future research.

These activities are discussed in further detail in the remainder of this section.
A review of the related literature examines existing solution approaches to the truck scheduling is considered. The literature review also evaluates the assumptions of previous research in this area and determines the effectiveness of the various existing solution approaches. In this section we discuss different level of decisions in cross-docking such as strategic, operational decisions. The design and operation of cross-docking facilities involve both tactical and strategic decision-making that can benefit from the application of operations research techniques. This is evidenced by the extensive literature review provided by different authors that we will discuss in strategic decisions section of literature review. In this section we study papers that focus on location of cross-docks layout design and cross-docking networks. We review some other decisions deal with midterm planning horizon, and long term planning horizon. Efficient operation and management of cross-docking is based on some decisions in the short term planning. These planning involve operational decisions in daily or weekly. The researches in this strategic level are grouping in different problems area of truck sequencing problem, assignment of dock doors, and vehicle routing that focuses on managing the products and picking them up from various manufacturer before arriving at the cross-dock and delivering them to multiple retailers after the process of consolidation at cross-docking terminal, and problems that are not specific for cross-docking such as product allocation, transshipment problem, scheduling of the internal resources and strategies for loading and unloading the goods.

In the section of literature review, first, we discuss the strategic decisions such as the location of cross-docks and layout design. Next, we introduce some papers related to the tactical problem in cross-docking networks. Finally, we describe the operational decisions such as truck scheduling , vehicle routing and dock door assignment. Our thesis is focused on the problem of truck scheduling. Truck scheduling problems have received large amount of attention in the recent decade and have contributed many challenging usage for optimization technologies. In literature review we mainly discuss papers that deal with the truck scheduling problem. In this section we classify and summarize existing literature according to the classification of (Boysen N. and Fliedner 2009).

Finally, in literature review we study that only a few papers deal with multiple dock doors in cross-docking and several authors consider a cross-dock with a single receiving and a single shipping door to study the truck scheduling problem. Also, we find that some articles consider a more realistic cross-dock with multiple dock doors, but they only deal with one of the scheduling of inbound or outbound trucks. It is assumed that the outbound trucks or inbound trucks are already scheduled or are assigned on a mid-term horizon. Also, some articles formulate the problem of truck scheduling as a mathematical model that their computational study shows that the exact mathematical models can be used to solve smaller problem instances optimally within minutes. But, it is inefficient and impractical for medium to large size problems because of increased computational time requirement. Therefore, to increase solution efficiency, a heuristic or metaheuristic algorithm is needed. So, this proposed research will study the truck scheduling problem. Specifically, this research will focus on improving the truck scheduling problem in a cross-docking with multiple strip and stack doors. We also consider the scheduling of inbound and outbound trailers on a short-term horizon and assume that none of them is known in advance.

In next chapter, description of cross-docking problem, we study the problem statement and we describe our cross-docking problem. Distribution of customer’s demands, cross-docking terminal and storage, transshipment efficiency, transportation policies and sequence of incoming/outgoing trucks are discussed in detail. We explain in detail all the assumptions that are made in addressing this problem. We classify our project according to the classification of (Boysen and Fliedner 2009), any truck scheduling problem will at least consist of three basic elements: door environment, operational characteristics and an objective to be followed.

Next chapter, solution approach, will focus on description of metaheuristic approaches for truck scheduling problem of multiple-doors cross-docking. This section describes the Tabu search, the objective function and the solution approach for the truck scheduling problem. Tabu search is designed for the solution of optimization problems, is described in detail. The basic elements of Tabu search are briefly stated and defined; current solution, moves for generating different solutions, set of candidate moves, tabu restrictions, aspiration criterion, stopping criteria, intensification and diversification are discussed. Then we explain our tabu search for cross-docking problem in steps; Initial Solution including explanation of construction of initial solution and evaluation of them with objective function is defined. Generating new neighborhood for each solution and movements and exchange of incoming and outgoing trucks is discussed with examples. Finally evaluation of solutions in neighborhood and selection of the best among them is defined.

In next chapter; to analyze the solution approaches, we run the Tabu search algorithm for different problem instances; the instances are varied in number of doors, trucks and destinations; The objective function of the experiment is maximizing the direct transfer of products and the procedures discussed in Chapter 4 are implemented in C++, and the 31 problem instances of data are used to generate the results discussed in following sections. The result of Tabu search is compared with an iterative stochastic search embedded with a heuristic method to minimize the sum of cost of inventory holding.

Final results and conclusions of this research are discussed, along with areas for future research.

CHAPTER 2: LITERATURE REVIEW

The concept of cross-docking has attracted attention in industry and academia during last ten years. A major considerable number of research papers are published from 2004 on and it is expected to have more research on the topic of cross-docking the coming years (Van Belle, Valckenaers et al. 2012).

In published literature, many industries have reported considerable advantages due to application of cross-docking systems. Companies such as retail chains Wal-Mart (Bartholdi John J. and Kevin 2004), mailing companies such as UPS (Forger 1995), automobile producers such as Toyota (Witt 1998) explain that cross-docking is useful to apply if it is implemented and applied in a good manner.

Previous researches mainly investigate one of the following levels of decision in cross-docking: Decision problems that concern about short term planning horizon (operational) ; while some other decisions deal with midterm planning horizon, and long term planning horizon (strategic or tactical) (Dwi Agustina 2010). Efficient operation and management of cross-docking is based on some decisions in the short term planning. These planning involve operational decisions in daily or weekly. The researches in this strategic level are grouping in different problems area of (a) truck scheduling problem, (b) assignment of trucks to doors, (c) vehicle routing problem that focuses on managing the freights and picking them up from various suppliers before arriving at the cross-dock and delivering them to multiple destinations after consolidation, (d) and other problems for cross-docking such as product allocation, transshipment problem, scheduling of the internal resources and strategies for loading and unloading the goods.

Researches on strategic decisions focus on the place of cross-dock and layout design. The cross-dock could be a part of supply chain network individually or merged with more cross-docks.

In this section, first, the strategic decisions such as the location of cross-docks and layout design are discussed. Next, the papers related to the tactical problem in cross-docking networks are introduced. Finally, the operational decisions such as vehicle routing problem, truck to door assignment and truck scheduling problem is described.

2.1 Strategic decisions

2.1.1 Location of cross-docks

Companies have to decide the location of cross-docks in their first steps of design of a distribution network. This subject has attracted considerable amount of attention in recent years.

Sung and Song (Sung C.S. and Song 2003) study network design problem. They consider the location of cross-docking centers and also the allocation of trucks for the shipping and transportation services. In this considered problem, freights are transported from manufactures to final destinations by a cross-dock and the direct transportations are not considered. In this study the demands are assumed to be known and the allocation of vehicles has to be made by considering the vehicle capacity and service time restriction. Sung and Song(Sung C.S. and Song 2003) solve the location problem by an Integer programming model. The objective of this research is to minimize the cost of locating cross-dock and the cost of allocating trucks by finding the best allocation of cross-dock. A Tabu search algorithm is proposed for the model.

In 2008, Sung and Yang (Sung C.S. and Yang 2008) extended their work in 2003 and proposed an improved Tabu search. They modeled a branch and price method and also a set-partitioning-based formulation of the problem as an exact algorithm.

Gümüs and Bookbinder (Gümüş and Bookbinder 2004) study the problem of cross-dock layout; a linear programming model is proposed to solve the problem of network design. The objective of this research is to minimize the total cost.

In (Chen 2006), objective of their model is to minimize the cost of transportation and inventory. Linear programming, Tabu search and Simulated Annealing is proposed.

In 2003, a different study is performed by Jayaraman and Ross (Jayaraman V. and Ross 2003). They proposed a model in which freights are transported from a supplier to distribution centers and then are shipped from cross-docks to the final destinations. The objective of this paper is to minimize the total cost of cross-dock opening and transportation cost. Simulated Annealing approach is proposed.

In 2007, Ross and Jayaraman (Ross and Jayaraman 2008) extended their model. Genetic Algorithm, Tabu Search and Simulated Annealing are proposed to solve their previous model.

2.1.2 Layout design

Many literatures, believe that a good layout could significantly affect the operation inside the cross-docking terminal.

Bartholdi and Gue (Bartholdi John J. and Kevin 2004) study different shape for layout of cross-dock. In this study, they measure the labor costs for different shapes.

Werners and Wülfing (Werners and Wüllfing 2010) study a model to reduce internal transports costs. The objective of their study is to minimize the travel distances between the endpoints and dock doors. Linear assignment problem, Mixed-integer linear programming model is proposed.

2.1.3 Cross-docking networks

In some papers, a network with one or more cross-docks is considered. The main objective of these papers is optimizing the flow of goods with minimizing the costs.

Lim et al. (Lim 2005) study the problem of transshipment with manufacturer and end customer time windows. Their objective is to minimize the cost flow. Their objective should meet the time window and capacity constraints of vehicles. Integer Programming model is formulated.

The same problem is developed by Miao et al. (Miao 2008) by considering special case of the problem. They restrict only one delivery or departure within a time window. They also fix the departure and arrival times. Integer Programming model is formulated.

Similar problem with multiple cross-docks is solved by Chen et al. (Chen 2006). Integer Programming model is formulated to solve the problem. Simulated Annealing, Tabu search and a combination of both is also implemented to solve this problem.

2.2 Operational decisions

2.2.1 Vehicle routing

The problem of vehicle routing plays a great role in distribution management. In distribution area products are picked up at various suppliers and destined for a cross-dock and then after consolidation in cross-dock has to be delivered to multiple destinations. The problem of pickup and delivery of freights is included in the problem of vehicle routing. This problem takes the attention of researchers in cross-docking and vehicle routing simultaneously (Van Belle, Valckenaers et al. 2012).

Mosheiov (Mosheiov 1998) study the vehicle routing problem. The objective of this study is to find a minimum length tour for a capacitated vehicle.

Lee et al. (Young Hae 2006) study the problem of vehicle routing. The objective of their work is to find an optimal vehicle routing schedule for both pickup and shipment of products. An Integer Programming model is formulated to solve this problem. Also, a heuristic algorithm based on a Tabu search algorithm is proposed.

Liao et al. (Liao, Lin et al. 2010) also study the vehicle routing problem. The objective of this study is to find the minimum number of vehicles and minimizing the sum of transportation and operational cost. A Tabu search algorithm is proposed.

Tzoreff et al. (Eilam Tzoreff 2002) study the vehicle routing problem over a graph. The objective of this study is to minimize the length tour for a capacitated vehicle. The objective should satisfy the demands of delivery and pickup, vehicle capacity constraint. A linear time algorithms is formulated to solve this problem.

Since the considered problem is NP-hard (Young Hae 2006) in several researches, metaheuristics algorithms are used. Lee et al. (Young Hae 2006), applied Tabu search.

2.2.2 Dock door assignment

On the moment of arrival of incoming and outgoing trailers, the cross-dock organiser should decide which dock door could be assigned to the trailers. Freights are moved by forklift from incoming platforms to temporary storage and then to outgoing platforms or directly from incoming to outgoing. In some papers, it is considered that the number of dock doors is not as much as trucks, so there have to be scheduling for the dock doors.

One of the operational decision in cross-dock is the problem of dock doors assignments. This decision may be executed on a short-term or mid-term planning (Van Belle, Valckenaers et al. 2012). In some papers this problem is considered on a mid-term planning horizon. In this type of decisions, the manager fix the assignmenh of dock doors, Therefore, all the incoming trailers from the same suppliers or with the same final destinations are assigned to some and same strip doors. Although the fixed scheduling of doors provide easier situation for workers, but it reduces the flexibility of cross-dock. Even if the cross-dock uses the fixed assignment of docks, for each significant change in the delivery of products, the scheduling of dock doors has to be reassigned (Van Belle, Valckenaers et al. 2012).

On the other hand, this truck to door assignment can be decided in a short term planning horizon. This specific kind of decision is appropriate for those companies that do not have the full information about the arrival sequence of incoming trailers from suppliers in advance. Also it is possible to have a combination of both types of assignments. In the literature, some papers consider the assignment of outbound trailers in a mid-term horizon and the assignment of inbound trailers in a short-term horizon (Van Belle, Valckenaers et al. 2012)".

Tsui and Chang (Tsui and Chang 1990) study the assignment of trucks to doors in a mid-term planning horizon. In their study no storage is allowed and the freights are shipped directly from incoming to outgoing trailers. The objective is to minimize the travel distance of the forklifts. A bilinear programming is formulated to solve this problem. Tsui and Chang (Tsui and Chang 1992) proposed branch-and-bound algorithm to solve the dock door assignment problem.

The approach of Tsui and Chang (Tsui and Chang 1990) is extended by Cohen and Keren (Cohen and Keren 2009). The same mathematical model is adapted. A Non-linear Mixed Integer problem model is formulated for small sized problems. Also a heuristic algorithm is applied for real size problems.

The same problem is studied by Bermúdez and Cole(Bermudez 2001). Bermúdez and Cole study the assignment problem by assuming that all the doors can be assigned to either an origin or a destination. Same mathematical model of Tsui and Chang (Tsui and Chang 1990) is applied. The objective of their study in minimizing the total weighted travel distance. A Genetic Algorithm is also proposed to solve this problem.

Oh et al. (Oh 2006) study the assignment problem in a mail distribution center. The objective of their study is to minimize the total travel distance inside the cross-dock by finding the best assignment of destinations to stack doors. A Non-Linear programming model and two heuristic methods is proposed to solve this problem.

Bartholdi and Gue (Bartholdi John J. and Kevin R. Gue 2000) study the layout of a cross-dock. They study that layout of a terminal affect the labor costs. The objective of their works is to find an optimal layout by minimizing the total labor cost. A mathematical model and Simulated Annealing is proposed to solve the assignment problem.

Gue (Kevin R. and Gue 1999) study the layout of cross-docks. A local search algorithm is proposed to find the optimal layout with the lowest labor cost.

2.2.3 Truck scheduling

One of the important decisions in daily cross-docking operations is truck scheduling. Determination of suitable sequence of trucks provides good product flow, minimum processing time and minimum total cost. In distribution network, too many centers reduce flow consolidation and introduce unnecessary inventory delay. On the other hand, too few centers will cause flow travel long distances; and thus, it can differ the transportation costs.

The assignment problem which we discussed in previous part is part of scheduling problem. In the assignment problem, truck to door assignment is considered and in scheduling problem, trucks use the doors as resources.

The problem of Truck scheduling has received significant attention in the recent years. This section discusses papers that deal with the truck scheduling. Boysen and Fliedner (Boysen N. and Fliedner 2009) introduce a classification of deterministic truck scheduling. In this section, with the help of this classification, existing literature is reviewed. Boysen and Fliedner (Boysen N. and Fliedner 2009) study three elements of truck scheduling problem as: door environment, operational characteristics and an objective to be followed.

Van Belle (Van Belle, Valckenaers et al. 2012) summarized the papers according to this classification scheme in Table 2-1.

Table 2-1 - Truck scheduling problem – Characteristics of articles - source: (Van Belle, Valckenaers et al.).

Papers	Doors#	Internal transport	Service mode	Preem-zption	Arrival pattern	Departure time	Interch-angeability	Temporary storage
(Chen and Lee 2009)	2	ns	Exclusive	No	Concentrated	No	Truck	Yes
(Feng and Kailei 2009)	*	ns	Exclusive	No	Concentrated	No	Truck	Yes
(Yu and Egbelu 2008) (Vahdani and Zandieh 2010) (Boloori Arabani, Fatemi Ghomi et al. 2010)	2	Automated	Exclusive	No	Concentrated	No	Allowed	Yes
(Boysen, Fliedner et al. 2010)	2	*	Exclusive	No	Concentrated	No	Allowed	Yes
(Forouharfard and Zandieh)	2	ns	Exclusive	No	Concentrated	No	Allowed	Yes
(Boloori Arabani A., Fatemi Ghomi et al. 2011)	2	Automated	Exclusive	No	Concentrated	Outbound	Allowed	Yes
(Larbi, Alpan et al. 2010)	2	ns	Exclusive	Yes	Scattered	No	Destination	Yes
(Alpan, Larbi et al. 2010)	*	ns	Exclusive	Yes	Scattered	No	Destination	Yes
(Boysen N. and Fliedner 2009)	*	ns	Exclusive	No	Concentrated	Outbound	Destination	Yes
(Claudia, Michael et al. 2009)	*	Manually	Exclusive	No	Concentrated	No	Truck	Yes
(Wang and Regan 2008)	*	Manually	Exclusive	No	Scattered	No	Destination	No
(Douglas, Stanfield et al. 2005; Douglas, Stanfield et al. 2008),(McWilliams 2010)	*	Automated	Exclusive	No	Concentrated	No	Destination	No
(Bartz-Beielstein , Chmielewski et al. 2006)	*	Manually	Exclusive	No	Concentrated	Both	Destination	Yes
(Lim, Ma et al. 2006),(Miao, Lim et al. 2009)	*	Manually	Mixed	No	Scattered	Both	Truck	Yes
(Boysen 2010)	*	Manually	Exclusive	No	Concentrated	No	Truck	No
(Shakeri, Yoke et al. 2008), (Li, Low et al. 2009)	*	Manually	Mixed	No	Concentrated	No	Truck	Yes

Table 2-2 - Truck scheduling problem – classification of Boysen and Fliedner 2009 - Source: (Van Belle, Valckenaers et al.)

Papers	Notation
(Chen and Lee 2009)	$[E2 \mid tj=0 \mid Cmax]$
(Feng and Kailei 2009)	$[E \mid tj=0 \mid Cmax]$
(Yu and Egbelu 2008)	$[E2 \mid change \mid Cmax]$
(Vahdani and Zandieh 2010)	
(Boloori Arabani A., Fatemi Ghomi et al. 2011)	
(Boysen, Fliedner et al. 2010)	$[E2 \mid pj=p,change \mid Cmax]$
(Forouharfard and Zandieh)	$[E2 \mid change \mid \sum Sp]$
(Boloori Arabani A., Fatemi Ghomi et al. 2011)	$[E2 \mid change \mid *]$
(Soltani and Sadjadi 2010)	$[E2 \mid pmtn,no\text{-}wait,change \mid Cmax]$
(Larbi, Alpan et al. 2010)	$[E2 \mid pmtn \mid *]$
(Alpan, Larbi et al. 2010)	$[E \mid pmtn \mid *]$
(Boysen N. and Fliedner 2009)	$[E \mid tio,fix \mid \sum wsUs]$
(Claudia, Michael et al. 2009)	$[E \mid tio \mid *]$
(Wang and Regan 2008)	
(Douglas, Stanfield et al. 2005), (Douglas, Stanfield et al. 2008),(McWilliams 2010)	$[E \mid pj=p,no\text{-}wait,tio \mid Cmax]$, $[E \mid no\text{-}wait,tio \mid Cmax]$, $[E \mid pj=p,no\text{-}wait \mid *]$, $[E \mid no\text{-}wait \mid *]$
(Lim, Ma et al. 2006),(Miao, Lim et al. 2009)	$[M \mid limit,tj=0 \mid *]$, $[M \mid limit,tio \mid *]$
(Boysen 2010)	$[E \mid pj=p,no\text{-}wait,tj=0 \mid \sum Co]$, $[E \mid pj=p,no\text{-}wait,tj=0 \mid *]$, $[E \mid pj=p,no\text{-}wait,tj=0 \mid \sum To]$
(Shakeri, Yoke et al. 2008) , (Li, Low et al. 2009)	$[M \mid tio \mid Cmax]$

(Van Belle, Valckenaers et al. 2012), classify papers according to the classification proposed by Boysen and Fliedner (Boysen N. and Fliedner 2009) for scheduling problem. (see Table 2-2). Boysen and Fliedner specify several attributes for each main element. For instances, they specify service mode and number of dock doors attributes for element of door environment; pre-emption, arrival times, processing time and deadlines for element of operational characteristics; And finally, for each truck scheduling problem the optimization will be evaluated by some objective. For instance, objectives are classified to minimization of makespan, tardiness, the completion time and the maximum lateness.

There are several papers in the literature which deal with this scheduling problem. Some study a cross-dock with a single inbound and outbound stack door. The problem of Truck scheduling in these papers focuses on the sequencing of the incoming and outgoing trailers.

In (Chen and Lee 2009) , study the truck scheduling problem by a two-machine flow shop method. In their study the objective is to find an optimal sequence of inbound and outbound trailers in order to minimize the makespan. They assume that the capacity of storage is infinite and all the trailers are available at time zero. A branch-and-bound algorithm is applied to solve the problem.

Chen and Song (Feng and Kailei 2009) , extend this problem to the two-level hybrid truck scheduling problem. The objective of their work is to minimize the makespan. A Mixed Integer programming for small size problem is proposed. They also applied different heuristics to solve the problem for large scale instances.

Yu and Egbelu (Yu Wooyeon and Egbelu 2008) study the problem of truck scheduling. They simplify the cross-docking to single door cross-docking. The objective is to find an optimal scheduling sequence for inbound and outbound trailers in order to minimize the makespan. A mathematical model applied for small scale instances. A heuristic algorithm is also implemented for large scale instances.

Vahdani and Zandieh (Vahdani B. and Zandieh 2010) study the truck scheduling problem. They apply five metaheuristics algorithms: Tabu search, Genetic algorithm, Simulated Annealing, Variable Neighbourhood search and Electromagnetism-like algorithm. The objective is to minimize total operation time. They use the solution from the heuristic method by Yu and Egbelu (Yu Wooyeon and Egbelu 2008) as their initial solution. The metaheuristics are compared to each other according to the makespan and CPU time.

Arabani et al.(Boloori Arabani A. and Fatemi Ghomi 2011) study the truck scheduling problem by implementing some metaheuristics to find optimal scheduling of inbound and outbound trailers sequences. The objective is to minimizing the total operation time. Tabu search (TS), Genetic algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony optimization (ACO) and Differential Evolution (DE) is implemented.

Boysen et al. (Boysen N. and Fliedner 2010) study the truck scheduling problem. An Integer programming model is applied. They simplified the cross-docking to one door cross-docking. They propose a decomposition approach with two sub-problems of fixing inbound trailer sequences and determine the optimal outbound trailer sequences and vice versa.

Forouharfard and Zandieh (Forouharfard and Zandieh) study the truck scheduling problem in cross-docking. The objective is to minimize the total number of freights that pass trough storage. An imperialistic competitive algorithm approach is proposed to solve this problem.

Arabani et al. (Boloori Arabani A. and Fatemi Ghomi 2011) study the truck scheduling problem according to just-in-time method. The Objective is to minimize earliness and tardiness of trailers. Some metahueristics are implemented to solve this problem, Genetic algorithm (GA), Particle Swarm Optimization (PSO) and Differential evolution (DE).

Vahdani et al. (Vahdani B. and Zandieh 2010) study the truck scheduling problem with temporary storage. An Integer programming model is formulated for small scale instances. Two metaheuristics of Genetic algorithm and Electromagnetism-like algorithm is also implemented for larger scale of instances. Soltani and Sadjadi (Soltani and Sadjadi 2010) implemented two metaheuristics of Hybrid Simulated Annealing (SA) and Hybrid Variable Neighborhood search (VNS) to solve the same problem.

Larbi et al. (Larbi, Alpan et al. 2010) study the transshipment scheduling problem of only outbound trailers in a single door cross-dock. The objective is to minimize the total cost, storage and preemption, by finding the optimal schedule of outbound trailers.

Alpan et al. (Alpan) study the cross-docking problem with the objective to find optimal truck scheduling in order to minimize the total costs related to the transshipment operations at the warehouse. A Bounded Dynamic Programming approach is proposed. They use Dynamic Programming (DP) technique to find optimal scheduling. Then they formulate intelligent bounds gained from experimental results.

Some papers study multiple inbound and outbound doors, but they only consider scheduling of inbound trailers.

Boysen and Fliedner (Boysen N. and Fliedner 2009) study the problem of truck scheduling and they fix outbound schedule. The objective is to minimize the weighted number of products delayed up to the next day.

Rosales et al. (Claudia R. and Rosales 2009) study the scheduling of inbound trailers. A Mixed-Integer Linear program is formulated. The objective is to find an optimal allocation of incoming trailers to doors in order to minimize the operational cost.

Wang and Regan (Wang 2008) study the truck scheduling problem with the objective of minimizing the time freight spends in a cross-dock. Dynamic simulation models are proposed to compare different strategies.

McWilliams et al. (Douglas L. McWilliams and Paul M. Stanfield 2005; Douglas 2008) study the truck scheduling problem in parcel delivery industry. The objective is to find an optimal schedule to minimize the time span. McWilliams et al. in paper of (Douglas L. McWilliams and Paul M. Stanfield 2005) study the problem with products with the same size. In paper of (Douglas 2008), this assumption is relaxed. A simulation-based scheduling algorithm that uses a Genetic algorithm is applied to solve this problem.

McWilliams in (McWilliams 2010) propose a decomposition approach to answer this problem. The objective of their work is to minimize congestion and thus the time span. The local search and Simulated Annealing (SA) algorithms are implemented for this problem. They compare their results with an existing Genetic algorithm. In (McWilliams 2009), McWilliams extended the previous work by applying the dynamic load balancing.

Baptiste and Maknoon (Baptiste P. and Maknoon 2007) study the truck scheduling problem for single door cross-dock. The objective is to maximize the direct transformation of products. The local Tabu search integrated with Dynamic programming and a heuristic method is proposed to solve this problem.

There are several other papers that study the problem of scheduling the inbound and outbound trailers. Lim et al. (Lim 2006) study the truck scheduling with assuming the loading and unloading of products in a fixed time window. An Integer Programming is formulated to solve this problem. The objective is to minimize the total shipping distances. A Tabu search and a Genetic algorithm is also implemented to solve this problem.

This approach is extended in (Miao 2009). They consider the travel time between the dock doors. The objective is to minimize the operational cost.

Boysen (Boysen 2010) study the a truck scheduling problem. They assume that the capacity of storage inside the warehouse is zero. The objective is to minimize the processing time, flow time and tardiness of outbound trailers. Dynamic programming and Simulated Annealing are implemented to solve this problem.

Maknoon and Baptiste (Maknoon and Baptiste 2009) study the truck scheduling problem by considering the importance of platform’s internal movement of products. The objective is to maximize product flow that is transferred directly. Dynamic programming and heuristic approach are proposed to solve this problem.

Shakeri et al. (Shakeri 2008) study the truck scheduling and assignment of truck to doors problem. The objective is to minimize the makespan. A Mixed Integer programming model is formulated to solve this problem.

Li et al. (Li ZP 2009) also study the truck scheduling and assignment of truck to doors problem. A Mixed Integer programming model and a search heuristic is proposed to solve this problem. The objective is to minimize the total operational time

2.3 Summary of Literature Review

This chapter reviewed the literature available for the cross-docking problem. In this part we only consider the problems that are specific for the problem of cross-docking. In this part we discussed the strategic decisions such as the location of cross-docks and the layout design. The intermediate temporary storage is also studied. We studied the articles which focus on tactical problem of cross-docking. Further, papers that deal with operational decision are discussed. These papers study the concepts of truck scheduling, vehicle routing and assignment of dock doors.

We noticed that a cross-docking gain attentions during the recent years. General aspects of cross-docking is studied in many papers. Several papers study the advantages of cross-docking and suitability of its implementation for organizations. However, some other papers study specific subjects of cross-docking. These papers deal with truck scheduling problem, truck-to-door assignment or vehicle routing problems. Despite the attentions, not all types of cross-docking problem are studied. Most papers deal with simplified version of cross-docking with single strip and stack door. Also, some papers study the cross-docking with multiple doors, but they assume that one of the scheduling of inbound or outbound trucks is fixed. They assume that this assignment of scheduling for inbound or outbound trucks is applied on a mid-term horizon.

Some papers formulate this problem as a mathematical model that their computational study shows that the exact mathematical models can be used to solve smaller scale instances optimally within reasonable time. But, it is not efficient and practical for medium to large size scale instances because of increased computational time requirement. Therefore, to increase solution efficiency, a heuristic or metaheuristic algorithm is needed.

So in general, more researches are required to deal with multiple doors with unknown schedule of both inbound and outbound sequences and application of metaheuristic algorithms. This proposed research will study the truck scheduling problem. Specifically, this research will focus on improving the truck scheduling problem in a cross-docking with multiple strip and stack doors. We also consider the scheduling of inbound and outbound trailers on a short-term horizon and assume that none of them is known in advance.

CHAPTER 3: PROBLEM DESCRIPTION

3.1 Problem Overview

In the logistic network there are two types of cross-docking terminals: Satellite and Hub. In the satellite terminal, the inbound trucks arrive at night; they unload their products and in the next morning they depart the platform for the final destination. However, the in the Hub terminals, the inbound trucks arrive and depart during the day. Beside trucks arrival both terminal have same operations.

The problem of cross-docking consists of a distribution network including of customers, suppliers, cross- docks, and vehicles. The customers demand the products from the suppliers. These products are delivered from manufacturers to their customers through the cross-docks. Most distribution centers are long and narrow platform with doors around it. The number of doors depends on the size of terminals." Large terminals may have around 500 doors" (Kevin R. and Gue 1999). Inside the terminal variety of material handling tools such as manual forklifts and pallet jacks are used to carry freights. In each cross-docking center there are two kinds of doors: receiving and shipping. At the receiving door, inbound trucks are parked to be unloaded; at the shipping door, empty outbound trucks are assigned to load for specific destination. Within each cross-dock, products inside the inbound trucks are sorted and consolidated to multiple outbound trucks. At the receiving door, if the outbound trucks for the same destination of the unloaded products are available, then the products are transferred directly to the shipping doors; otherwise, the products are transferred to the storage area for future reshipment.

The efficiency of product transshipment may be measured by the number of freights that move directly through the platform (Baptiste P. and Maknoon 2007). Product flow is affected by some factors of congestion, the moving path and travel distance from inbound to outbound doors. In each cross-docking platform the sequence of incoming/outgoing trucks and unloading/loading policies affect the product movements (Baptiste P. and Maknoon 2007).

Products in cross-docking terminal are unloaded from incoming trailers available at the strip door, then they are sorted according to their final destinations and are moved to dispatch points.

They are directly loaded onto shipping trailers for the first possible delivery to the final customer (Boysen N. and Fliedner 2009).

Most companies who are successful in implanting the cross-docking efficiently, prefer not to have any intermediate storage inside the warehouse or if it is needed the storage is in small capacity. If products requested by the customer are not delivered on time, the supplier will face stock shortage, back orders and unsatisfied customers (Boloori Arabani A. and Fatemi Ghomi 2010).

Therefore the most important operation decision in such cross-docking systems is to provide and establish coordination between the scheduling of inbound and outbound trailers. It is essential to specify the arrival and departure schedule of trailers in advance.

At cross docking terminal, if truck sequences are known in advance, the transferring patterns of products are affected by unloading order of products and their loading policies. In truck loading/unloading process, there could be some technical restrictions. For example, items in front should be unloaded first or fragile boxes should be loaded last. However, in front of the doors, there is a staging area for products. If the arrival time and the contents of each truck for the destination are known in advances, the system can plan robust process of loading and unloading to reduce the total cost. However most of the platform does not have the perfect information of arrival time. In this situation proper algorithms should be applied to sequence the trucks in optimal way.

We define different transportation policies: 1) Fill the outbound trucks by all the products from storage. 2) Fill the outbound trucks by all the products directly transferred from receiving door. The products in storage send by the last truck departing to the destination. 3) Fill the outbound trucks by mixture of products from storage and products directly transferred from receiving door. In the problem of cross-docking, we deal with different sequencing problems: 1. Order of incoming trucks; 2. Order of outgoing trucks; 3.Order of loading products; 4. Order of unloading products; 5. Policy of loading; 6. Policy of unloading. In this research, without loss of generality we do not consider loading/unloading order of products and focus on optimal loading/unloading policy and trucks sequencing.

In this thesis, the operations inside the warehouse or distribution center are not considered. The time related to scanning and sorting operations is considered constant number. In this project, we assume that there is a temporary storage with unlimited capacity. The inbound trailers carry the freights for different final customers; if the outbound trailers for the products arriving to the cross-dock are not available, the products are stored temporary in the storage until the appropriate outbound trailer arrived into the stack dock. In this thesis we assume that inbound and outbound trailers must stay in docks until they finish their task of loading or unloading once they come into docks and preemption is not allowed.

The objective of this research is to find the best truck docking sequences for both the inbound and the outbound trucks to maximize the throughput rate of the cross docking process. In this project we evaluate a given solution to our algorithms for truck scheduling due to maximum direct transformation of products as the objective function. However we do not consider the operations inside the warehouse (because for example the packing of inbound trailers is usually not known at the cross-dock prior to opening the respective trailer, Consequently, we neglect the influence of packing times and include it in the transportation time lag.).

This thesis focuses on application of metaheuristic search algorithm of Tabu for improving the efficiency of multiple-doors cross-docking with unknown sequence of incoming and outbound trailers. The main objective is to maximize the direct flow of products from origin trailer to the correct destination trailers. The maximum direct transfer of products is considered for objective function, while most previous research’s objective function is based on minimizing the makespan.

3.2 Problem Statement

This research focuses on developing a solution method to determine the optimal sequence of inbound and outbound trailers with the objective of maximizing the direct transfer of shipments. The problem statement of truck scheduling for multiple-doors cross-docking problem is shown in Figure 3-1.

Truck Scheduling Problem Statement
Given the following: 1. Trailer characteristics ▪ Weight ▪ Number of trailers 2. Freight characteristics ▪ Number of handling units ▪ Origin and destination 3. Number of dock doors 4. Number of destinations Determine the optimal sequence of inbound and outbound trucks to maximize the direct flow of products from a set of origin trailers to the correct final destination trailers.

Figure 3-1 -Truck Scheduling Problem Statement

In practice, product transshipment has various layouts. In this research the layout is being considered to multiple incoming and outbound doors. In this model an incoming trailer arrives at inbound door and unloads freights for various customers. If the shipping truck is going to the fine destination, the products are moved directly to outbound trucks, unless, the freights are moved to a temporary storage. In order to focus on these movements, we consider the model of cross-docking platform with multiple receiving and shipping doors and we assume the incoming and outgoing sequences are not known a priori.

In our problem, we have a storage area with unlimited capacity. The capacities and numbers of inbound and outbound trailers are equal. Each inbound truck may contain goods for several final destinations. All inbound and outgoing trailers are available at time zero. Also we know the arrival time of each inbound trailers, as well as their contents and their position in the. We apply the policy of FIFO; first inbound trailer arriving in the cross-dock will be assigned to one of the unoccupied inbound docks, in unloading of the trailers.

The following assumptions are made in addressing this problem:

- Each inbound trailer must leave the incoming door when it is fully unloaded. Also, each outbound must trailer leaves the outgoing door when it is fully loaded.
- The storage capacity inside the warehouse is assumed unlimited.

- The operations inside the cross-dock such as sorting, merging and packing are not considered.
- The time of loading, unloading and transfer are not considered and they are constant.
- All inbound and outbound trucks are available at time zero.
- Each shipping trailer departs for only one destination.
- The number of receiving and shipping freights is equal.
- The products inside the inbound trailers are for different destinations while products inside the outbound trailers are just for one destination.

According to the classification of (Boysen N. and Fliedner 2009), three basic elements: door environment, operational characteristics and an objective could be discussed. We will classify our project due to their classification as bellow:

3.2.1 Door environment

3.2.1.1 Service mode

In this research, an intermixed sequence of incoming and outgoing trailers to be processed per dock door is allowed.

3.2.1.2 Number of dock doors

Referring to the paper of (Kevin R. and Gue 1999) a terminal may contain more than 500 doors. In our research we consider multiple doors and the number of dock doors can be restricted to a given number k, where k can be any positive integer.

3.2.2 Operational characteristics

3.2.2.1 Preemption:

In this research we do not allow the preemption of truck processing. The operation of loading or unloading of trailers could not be interrupted. Only the Full trailer is removed from the dock.

3.2.2.2 Arrival times:

In this project we assume that we know or we can handle the arrival time of inbound trucks. Trucks are already waiting on the yard and readily available to be called up.

3.2.2.3 Processing time:

We consider that all the trucks have an equal processing time whenever the truck capacities as well as the number and their of products per vehicle do not strongly differ(Boysen 2010) . In our research, we consider that the freights are of comparable size and all trailer loads resemble a representative average truck load.

3.2.2.4 Intermediate storage:

In this research we consider an available stock space which is unlimited by a given capacity.

3.2.2.5 Assignment restrictions:

In our research there is no restriction to be considered. Any dock door which is unoccupied could be a possible choice for trailer processing.

3.2.2.6 Outbound organization:

In this research we consider that an outbound trailer is able to leave the terminal as soon as its predefined set of products is loaded.

3.2.2.7 Interchangeable products:

In this research we consider that the number products to be loaded per outbound trailer might be defined, so that freight units of a respective type can satisfy any shipping trailers' demand for this product.

In this study, our interest is in application of Tabu search for optimizing the truck scheduling problem. A formal presentation of a metaheuristic algorithm of Tabu search is presented in this section, along with a discussion of the model. The introduction and characteristic of Tabu search are presented first. Then the truck scheduling model is developed, followed by discussion about our model.

Several methods have been studied to solve single door cross-docking problem, mathematical methods converge to good solutions for small instances of the problem; but their large computational complexity prohibit their usage in practice for larger instances.

In this thesis we explain the algorithm of Tabu search for solving the problem of cross-docking with different problem instances. We demonstrate that Tabu search which has recently gained a lot of attention in the operations research community is very well suited to solve truck scheduling in Cross-docking problem. The comparison of Tabu search with mathematical methods shows that Tabu search is at least as powerful as the exact methods while it is efficient with fastest algorithm for large problem instance. The fact that it is a search which does not converge to a single solution but rather explores the search space in an intelligent way bears another significant advantage. Tabu search can produce a list of locations at which the objective function is very close to locations of good local extreme so this algorithm can corresponds to different solutions. In this project, we conclude that Tabu search is more suitable than mathematical models. If we concern the runtime, the Tabu search is preferred for solving large-scale instances.

CHAPTER 4: SOLUTION APPROACH

The primary objective of this research is to increase the amount of products transferred directly from a set of origin trailers to the correct destination trailers. This objective will be achieved by developing a solution approach to determine a better scheduling of truck and maximizing the direct transfer of products. An objective function that approximates number of direct transfer of products from an origin trailer, travel to the correct destination trailer, load freight onto the destination trailer, and travel to the next origin trailer is used to measure amount of product's transformation obtained by the solution approaches.

This research will focus on developing metaheuristic approaches for truck scheduling problem of multiple-doors cross-docking and providing recommendations for integrating in future research. The following sections describe the algorithm of Tabu search, the objective function and the solution approach for the truck scheduling problem.

4.1 Introduction to Tabu search algorithm

In this study, a metaheuristic methodology based on Tabu search is developed. One of the most successful and widely used metaheuristics in optimization is Tabu search algorithm. Tabu search has been applied efficiently to many combinatorial optimization problems.

This algorithm is an intensive local search that uses its search history and memory (Hertz, Taillard et al. 1995). A Tabu list which is a short-term memory, stores the information or attributes of recently visited solutions to avoid short-term cycling and local solution; this algorithm records recently tried solutions in a short-term memory; this algorithm also uses a long-term memory that provides intensification and diversification (Hertz, Taillard et al. 1995).

The best solution among all other solutions in the neighborhood of the current solution is chosen as the new current solution, in each iteration; sometimes selection of best neighborhood may lead to an increase in solution cost. This solution is new current solution. In order to escape a local optimum, Tabu search accept solutions that leads to an increase in current solution cost.

The algorithm stops its search by a stop criteria; the stop criteria could be a fixed number of iterations. Some papers consider a maximum number of non-improved consecutive iterations as the stop criteria (Hertz 1995) (Gendreau M., C.C. Ribeiro et al. 2002; Gendreau M. and F. Glover 2003).

Tabu search starts by an initial solution which obtained through Greedy heuristic. The current solution is replaced by a neighbor that improves that improves the objective function of heuristic. Next section states the metaheuristic algorithm and explains each step.

Different computational experiments use Tabu search algorithm as a successful optimization technique. This algorithm is flexible, easy to implement and shows good behavior compared to almost all known techniques in solving optimization problems. This search algorithm is an iterative process includes moving from current solution to next solution which in its neighborhood. In each movement, it checks whether one should move to next step or stop on the current step. Tabu search keep the local information of current value of objective function. All information during the exploration process is also recorded in a memory. This information includes the best solution gained so far. Such information guides the algorithm to move from current solution to the next solution which is chosen in the neighborhood as the best solution. This could help the algorithm to decide if the current solution has been improved or not. The memory limits the choice to some subset of neighborhood of current solution by forbidding moves to some neighbour. This information provides the movement from one solution to other solution to be guided. Using the memory is helpful to forbid those moves that might lead to recently visited solutions. In each iterative exploration process, algorithm should also accept some non-improving moves to escape from a local minimum. If non-improving changes are possible, there could be the risk of visiting again a solution and cycling in one neighborhood of the solution space(Hertz 1995; Hertz, Taillard et al. 1995).

Tabu search short term memory is used to limit some changes likely to lead us back to recently visited solutions. However, in the search area we needed to intensify the search in some region of search space. These regions may contain some acceptable solutions. Therefore, it is needed to give a high priority to some solutions that are most potential to guide us to better results (Hertz, Taillard et al. 1995).

To intensify the search algorithm in promising areas, Tabu search first come back to one of the best solution gained so far and then increase the Tabu list size for a few number of iterations (Hertz, Taillard et al. 1995). The intensification will provide solutions far from the present one. The Tabu search algorithm intensifies one solution area during a few iterations and then it explores another region of search space(Hertz 1995). The exploration effort over different regions of search space is defined as diversification of exploration (Hertz, Taillard et al. 1995); Tabu search give a weights for these terms in such a way that both terms alternate during the search. Memories are used to save information of how often some solution attributes are found in previously visited solutions.

To provide diversification at each iteration, some regions and area of the neighborhood which contain solutions with higher number of visited count, could then be penalized. We can provide the search algoirhtm to visit other regions by diversification (Michel Gendreau 2005). “Diversification could be simply applied by performing several random restarts. Another way of exploring unvisited regions is to penalize solutions often visited or frequently performed moves. This method helps to escape from the current region; however solutions in new regions are not necessarily feasible”(Hertz, Taillard et al. 1995). The algorithm of Tabu Search, as described above, is reported in Figure 4-1. This figure specifies how to intensify and diversify the search(MALLBA-BA 2000).

In order to intensify the search, algorithm has to be implemented in a way of rewarding the solution. This function will maintain the current solution composition as much as possible. Diversification of the search could be performed by penalizing the solutions. By penalizing, changing of the current solution is allowed. Also, diversification can be implemented by exploring less explored areas in the search space of feasible solutions. In Figure 4-1, this is called escape. When the escape is applied, the search goes on in a new random area of the search space (MALLBA-BA 2000).

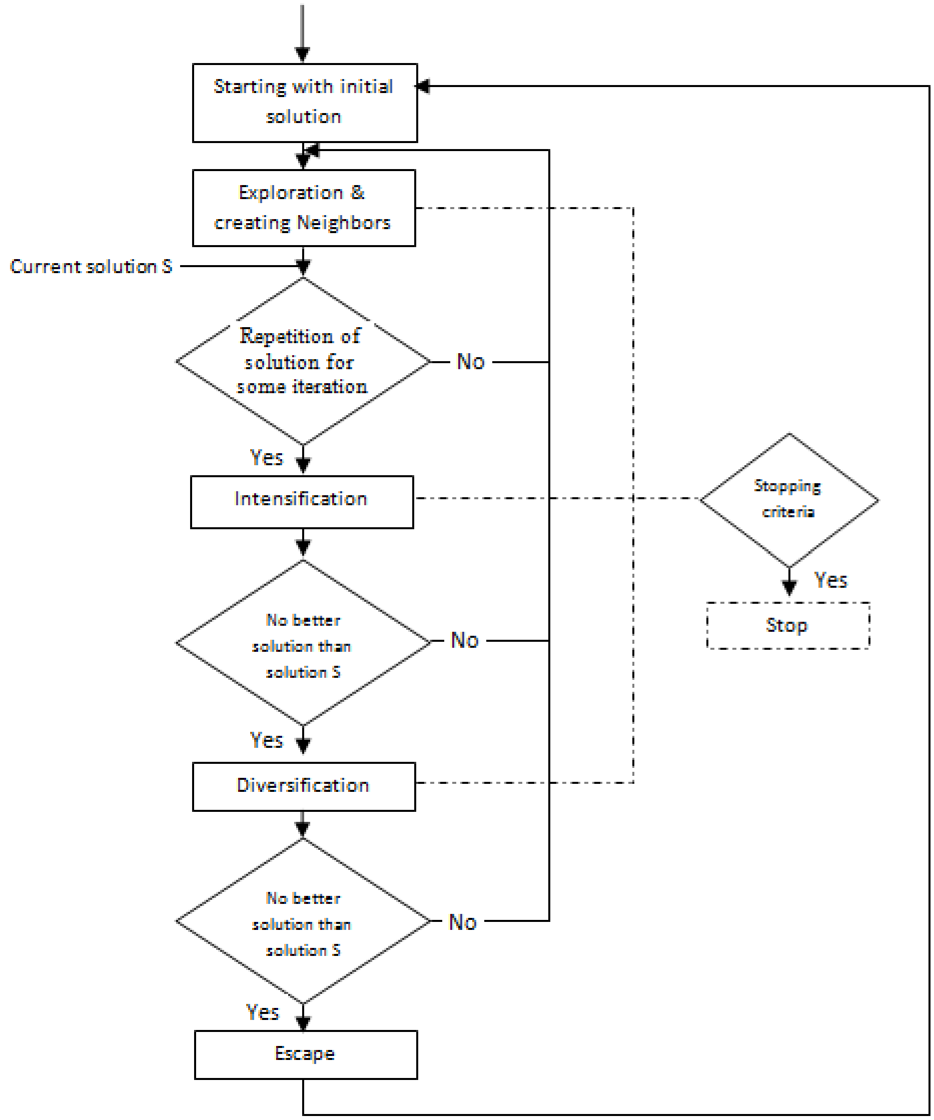

Figure 4-1 -Intensification and Diversification in Tabu search algorithm

In order to model the cross-docking problem, every trailer sequence (arrival and departure) is modeled as a solution. The solution contains a sequence schedule for the incoming trailer as well as a schedule for the outgoing trucks. For example one solution for six incoming trucks and six outgoing trucks can be seen in Figure 4-2. In this example, the cross-docking has two doors and three destinations of “A”,”B” and ”C”. In this figure, the subscript of “a” indicates arrival of the truck (inbound/outbound) and “d” indicates departure of the truck.

$5_{a,}$	$2_{a,}$	$5_{d,}$	$1_{a,}$	$2_{d,}$	$3_{a,}$	$1_{d,}$	$4_{a,}$	$3_{d,}$	$6_{a,}$	$6_{d,}$	4_{d}

(a) Incoming truck schedule.

$A_{a,}$	$B_{a,}$	$A_{d,}$	$C_{a,}$	$B_{d,}$	$A_{a,}$	$C_{d,}$	$B_{a,}$	$A_{d,}$	$C_{a,}$	$B_{d,}$	C_{d}

(b) Outgoing truck schedule.

Figure 4-2 - An Example of Truck Schedule Solution

In Figure 4-2(a), this solution has inbound truck five arrived in the first strip door and truck two arrived in the second strip door; truck five depart the dock door in the third position of sequence. In Figure 4-2(b), outgoing truck for destination “A” arrived in the first dock door and outgoing truck for destination “B” arrived in the second dock door. Shipping truck for destination “A” departs the dock door in the third position of sequence.

4.2 Initial solution

The Tabu search begins by creating a random solution to generate the initial solution. Once the initial solution has been created, a fitness function is performed on each solution. Based on the objective function of an individual solution a cost is assigned that is used during the selection process among other solutions. In this study, the sequence of arrived and departed inbound/outbound trailers is generated randomly to build initial solution. The initial sequences are feasible sequences. A sequence is feasible if it satisfies two constraints. First, there is no departed trailer before the arrival of the same trailer. Secondly, trucks inside the terminal at the available doors differ according to their destination.

After solution selection, the interchanges for each sequence are applied to create a new sequence (neighbor). The interchange is performed by selecting the trucks and exchanging the two trucks. A solution is considered as a neighbor solution of current solution if it is obtained by changing the sequence. The set of possible modifications must be applied to obtain a new sequence.

Our tabu search algorithm is explained as bellow:

The Tabu search starts with an initial solution; initial solution may be generated randomly or according to some sort of heuristics. Random initial solution is generated quickly; however, the metaheuristic needs more time and larger number of iterations to converge.

In order to speed up the search, we may use a Greedy heuristic. In this heuristic, inbound trucks are ordered in non decreasing number of products for each destination. The outbound trucks are ordered in non increasing number of products that are needed for each destination. Two sequences of incoming and outgoing trailers are generated as an initial solution. Initial solution is feasible and contains information of arrival and departures of trucks. We calculate the value of maximum directly flow for the Initial solution. This value is the best directly transfer of products so far. This initial solution is considered as current solution and the value of objective function for this solution is the current best value.

4.3 Neighborhood:

In next step, we generate neighbors for the current solution; a neighbor is generated by the using of a move operator that causes a small change to the current solution. In this thesis, our neighborhood is based on pair interchanges for some trucks in the sequence which will be discussed later as "*adjacent interchange for some of trucks*";

The main idea is to interchange a pair of trucks in inbound and outbound sequences; the pair interchange operator consists of exchanging the location of two trucks that are in the sequence. In multiple doors cross-docking we generate the neighborhood for every order of arrival/departure of inbound trucks and arrival/departure of outbound trucks.

In first step, we explain the main idea of interchanging the trucks inside the sequence; first we explain the interchange for a basic sequence which is related to the single cross-docking. These inbound/outbound sequences in single cross-docking do not have arrival and departure order of trucks; however in multiple cross-docking every sequence contains the order of arrival and departure for each truck. So, the interchange of trucks in multiple cross-docking is interchanging of arrived trucks with each other and also departed trucks with each other.

Suppose that the current receiving truck sequence and shipping truck sequence for a *single door* cross-docking are scheduled as follows:

Sequence of Inbound truck - $S_I = [S^I_1, S^I_2, S^I_3, \ldots, S^I_{N-1}, S^I_N]$
Sequence of Outbound truck- $S_O = [S^O_1, S^O_2, S^O_3, \ldots, S^O_{N-1}, S^O_N]$

For outbound truck sequence, interchanging of two trucks of 2 and 3 for above sequence of trucks, constructs a new sequence of:

$$S^O = [S^O_{1}, \mathbf{S^O_3}, \mathbf{S^O_2}, \dots, S^O_{N-1}, S^O_N]$$

The receiving and shipping truck sequence for ***multiple doors*** cross-docking are scheduled as:

$S^I = [\, S^I_{1a}, S^I_{2a}, S^I_{1d}, S^I_{3a}, S^I_{2d} \dots S^I_{(N-1)a},\ S^I_{(N-2)d}, S^I_{(N)a}, S^I_{(N-1)d}, S^I_{(N)d}\,]$

$S^O = [S^O_{1a}, S^O_{2a}, S^O_{1d}, S^O_{3a}, S^O_{2d} \dots S^O_{(N-1)a},\ S^O_{(N-2)d}, S^O_{(N)a}, S^O_{(N-1)d}, S^O_{(N)d}\,]$

In these sequences, we have two doors and "a" indicates the arrival of trucks and "d" means the departure of the truck. The neighborhood of the current shipping sequence would be as following:

$N_2^O = [\, \mathbf{S^O_{3a}}, S^O_{2a}, S^O_{1d}, \mathbf{S^O_{1a}}, S^O_{2d}, \dots S^O_{(N-1)a},\ S^O_{(N-2)d}, S^O_{(N)a}, S^O_{(N-1)d}, S^O_{(N)d},\,]$. (Interchange arrival shipping trucks 1 and 3 – Infeasible sequence),

$N_3^O = [\, S^O_{1a}, \mathbf{S^O_{3a}}, S^O_{1d}, \mathbf{S^O_{2a}}, S^O_{2d}, \dots S^O_{(N-1)a},\ S^O_{(N-2)d}, S^O_{(N)a}, S^O_{(N-1)d}, S^O_{(N)d},\,]$. (Interchange arrival shipping trucks 2 and 3 – Feasible sequence),

$N_4^O = [\, S^O_{1a}, S^O_{2a}, \mathbf{S^O_{2d}}, S^O_{3a}, \mathbf{S^O_{1d}}, \dots S^O_{(N-1)a},\ S^O_{(N-2)d}, , S^O_{(N)a}, S^O_{(N-1)d}, S^O_{(N)d},\,]$. (Interchange departure shipping trucks 1 and 2 - Feasible sequence),

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.

$N_{m-2}^O = [\, S^O_{1a}, S^O_{2a}, S^O_{1d}, S^O_{3a}, S^O_{2d}, \dots \mathbf{S^O_{(N)a}},\ S^O_{(N-2)d}, , \mathbf{S^O_{(N-1)a}}, S^O_{(N-1)d}, S^O_{(N)d},\,]$. (Interchange arrival shipping trucks N-1 and N - Feasible sequence),

$N_{m-1}^O = [\, S^O_{1a}, S^O_{2a}, S^O_{1d}, S^O_{3a}, S^O_{2d}, \dots S^O_{(N-1)a},\ \mathbf{S^O_{(N-2)d}}, S^O_{(N)a}, \mathbf{S^O_{(N-1)d}}, S^O_{(N)d},\,]$.(Interchange departure shipping trucks N-2 and N-1 - Feasible sequence),

$N_m^O = [\, S^O_{1a}, S^O_{2a}, S^O_{1d}, S^O_{3a}, S^O_{2d}, \dots S^O_{(N-1)a},\ \mathbf{S^O_{(N)d}}, S^O_{(N)a}, S^O_{(N-1)d}, \mathbf{S^O_{(N-2)d}},\,]$.(Interchange departure shipping trucks N-2 and N – Infeasible sequence).

There are many possibilities to generate neighborhood of the current solution; we limit our discussion to bellow movements.

- **Adjacent interchange for all the truck**
- **Adjacent interchange for some of trucks**

Adjacent interchange for all the trucks:

This movement provides us large space of solutions. Also the random interchanges could be applied for only the arrivals or departures of trucks.

For example; suppose that we have an inbound sequence for two dock doors and five trailers as bellow:

$$S^I = [S^I_{1a}, S^I_{2a}, S^I_{1d}, S^I_{3a}, S^I_{2d}, S^I_{4a}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}],$$

In order to interchange all the trucks, we select the truck in first position, S^I_{1a}, this truck will be interchanged by other arrival trucks such as S^I_{2a}, S^I_{3a}, S^I_{4a} and S^I_{5a}.

$N_1^I = [\mathbf{S^I_{2a}}, \mathbf{S^I_{1a}}, S^I_{1d}, S^I_{3a}, S^I_{2d}, S^I_{4a}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}]$, (interchange trailer one with trailer two – Feasible sequence)

$N_2^I = [\mathbf{S^I_{3a}}, S^I_{2a}, S^I_{1d}, \mathbf{S^I_{1a}}, S^I_{2d}, S^I_{4a}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}]$, (interchange trailer one with trailer three – Infeasible sequence)

$N_3^I = [\mathbf{S^I_{4a}}, S^I_{2a}, S^I_{1d}, S^I_{3a}, S^I_{2d}, \mathbf{S^I_{1a}}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}]$, (interchange trailer one with trailer four – Infeasible sequence)

$N_4^I = [\mathbf{S^I_{5a}}, S^I_{2a}, S^I_{1d}, S^I_{3a}, S^I_{2d}, S^I_{4a}, S^I_{3d}, \mathbf{S^I_{1a}}, S^I_{4d}, S^I_{5d}]$, (interchange trailer one with trailer five – Infeasible sequence)

It is necessary to evaluate the feasibility of the sequences after swapping the trucks. The sequence is feasible if there is no departure of truck before its arrival. Also it is not allowed to have two or more trailers with same destination available at the dock door; in above neighbors, N_1^I is feasible but the other sequences are not feasible.

Then we select truck in second position, S^I_{2a}, this truck will be interchanged by other arrival trucks such as S^I_{3a}, S^I_{4a} and S^I_{5a}.

The same process is applied for departed trucks and the rest of trucks.

For example: departed truck in position of three, S^I_{1d}, will be interchanged by other departed trucks such as S^I_{2d}, S^I_{3d}, S^I_{4d} and S^I_{5d}.

Although this movement provides us large space of solutions, but it should be considered that we have to find a wise way to reduce the calculation time for our algorithm; for each solution we evaluate the feasibility of sequences and then calculate the objective function. These steps demand large amount of time to perform. Therefore, we look for a way to reduce execution time for such approach. One idea is to interchange some of the trucks instead of all trucks. This movement generally aims to reduce the associated operating time and provide us new sequences as neighborhood.

Adjacent interchange for some of trucks:

In this movement, the goal for generating a new sequence is to find the brother(s) of each truck in its neighborhood and interchange only those trucks (for both arrival and departure); Suppose that we have an inbound sequence for two dock doors and five trailers as bellow:

$$S^I = [\mathbf{S^I_{1a}}, \mathbf{S^I_{2a}}, S^I_{1d}, \mathbf{S^I_{3a}}, S^I_{2d}, S^I_{4a}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}],$$

The brothers for trailer one (S^I_{1a}) and trailer two (S^I_{2a}) would be arrival trailer of three in forth position of sequence (S^I_{3a}). The brothers of an arrival truck will be the trucks between next two departures. In this sequence the truck between departed trucks of S^I_{1d} in position three and next departed truck in position five, is the arrival truck of $\mathbf{S^I_{3a}}$ in position of four. So the brother of arrived truck of $\mathbf{S^I_{1a}}$ and also $\mathbf{S^I_{2a}}$ is arrival truck of $\mathbf{S^I_{3a}}$ in position of four.

The possible interchanges would be as follows:

$N_1^I = [\mathbf{S^I_{3a}}, S^I_{2a}, S^I_{1d}, \mathbf{S^I_{1a}}, S^I_{2d}, S^I_{4a}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}]$, (swapping trailer one with trailer three – Infeasible sequence – have to be repaired)

$N_2^I = [S^I_{1a}, \mathbf{S^I_{3a}}, S^I_{1d}, \mathbf{S^I_{2a}}, S^I_{2d}, S^I_{4a}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}]$, (swapping trailer two with trailer three – Feasible sequence)

The brother of departed trailer of one in third position of sequence is departed trailer of two in fifth position of sequence. The possible interchange would be as follows:

$S^I = [S^I_{1a}, S^I_{2a}, \mathbf{S^I_{1d}}, S^I_{3a}, \mathbf{S^I_{2d}}, S^I_{4a}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}]$,
$N_3^I = [S^I_{3a}, S^I_{2a}, \mathbf{S^I_{2d}}, S^I_{1a}, \mathbf{S^I_{1d}}, S^I_{4a}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}]$ (swapping trailer one with trailer two, departures – Feasible sequence).

Generating a new set of neighbors is possible by continuing the same process as above; finally the brothers of trailer S^I_{3d} in position of seven of the sequence are trailers of S^I_{4d} and S^I_{5d}. And the neighbors by swapping these trailers are:

$S^I = [S^I_{1a}, S^I_{2a}, S^I_{1d}, S^I_{3a}, S^I_{2d}, S^I_{4a}, \mathbf{S^I_{3d}}, S^I_{5a}, \mathbf{S^I_{4d}}, \mathbf{S^I_{5d}}]$,
$N_{N-1}^I = [S^I_{1a}, S^I_{2a}, S^I_{1d}, S^I_{3a}, S^I_{2d}, S^I_{4a}, \mathbf{S^I_{4d}}, S^I_{5a}, \mathbf{S^I_{3d}}, S^I_{5d}]$, (swapping trailer four with trailer three, departures – Feasible sequence).
$N_N^I = [S^I_{1a}, S^I_{2a}, S^I_{1d}, S^I_{3a}, S^I_{2d}, S^I_{4a}, \mathbf{S^I_{5d}}, S^I_{5a}, S^I_{4d}, \mathbf{S^I_{3d}}]$, (swapping trailer three with trailer five, departures – Infeasible sequence – have to be repaired).

In this thesis, the movement of "*adjacent interchange for some of trucks*" is applied for generating new set of neighbors. This movement is the special case of interchanging all the trucks which contains only a subset of trucks to be interchanged.

After generating a new set of neighbors from the current solution, we need to repair the inbound sequences that are not feasible. Infeasible outbound sequences are rejected. Suppose that we permuted trailer in position of "i" with trailer in position of "k" to gain new neighbor from current solution; the new sequence is evaluated and it is infeasible; to correct this infeasible inbound sequences we do as follow;

Temporary Sequence ← Infeasible Neighbor of Sequence
i ← First position;
k ← Second position;

If permutation is for arrival trailer then
    Permute (k-1, k+1, Temporary Sequence, Infeasible Neighbor of Sequence);
If permutation is for departed trailer then
    Permute (i-1, i+1, Temporary Sequence, Infeasible Neighbor of Sequence);

For example, suppose we generated bellow sequence by interchanging arrival trucks of one and three in positions of one and four; this sequence is infeasible, because the departure of truck one is before its arrival:

$$N_1^I = [S^I_{3a}, S^I_{2a}, \mathbf{S^I_{1d}}, \mathbf{S^I_{1a}}, S^I_{2d}, S^I_{4a}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}],$$

According to above formulation:

Temporary Sequence ← Infeasible Neighbor of Sequence (N_1^I)
i ← First position (i=1)
k ← Second position (k=4)
If permutation is for **arrival** trailer then
    Permute (3, 5, Temporary Sequence, Infeasible Neighbor of Sequence);

So, we change trucks in position of three and five according to above formulation:

$$N_1^{I(repair)} = [S^I_{3a}, S^I_{2a}, \mathbf{S^I_{2d}}, S^I_{1a}, \mathbf{S^I_{1d}}, S^I_{4a}, S^I_{3d}, S^I_{5a}, S^I_{4d}, S^I_{5d}],$$

This sequence is feasible after above modification;

This algorithm of repairing the infeasible sequences works well for our solutions; the reason is the format of the inbound and outbound sequences. The sequences are formatted as arrival of trucks then their departures. It means that any arrival of a truck is followed by its departure. After interchanging the arrival trucks, the infeasibility of the sequence is due to its departure trucks positions which are placed before the arrival of trucks, therefore by changing the departed trucks positions after their arrival positions we are expecting to have feasible sequences. In the same way, after interchanging the departed trucks, position of arrived trucks may cause the infeasibility; changing the position of these arrived trucks placing before their departure positions could provide us feasible sequences.

In this thesis we apply the last type of movement for generating new neighborhood for each solution; In next step, after generating all neighbors and correcting the infeasible sequences, the best neighbour is selected among all;

We apply the strategy of Best improvement. In this strategy, a feasible solution in the neighborhood with the most improvement in the cost function is selected. However, this type of exploration may be time-consuming for large neighbourhoods. In multiple doors cross-docking problem, a feasible neighbor is an inbound/outbound sequence that the number of arrived trucks is more than the departed ones.

In this study, our interest is in maximizing the number of products flow directly within doors that would lead to minimizing the makespan of cross-docking terminal. Based on that, two extreme policies are defined to load trucks. The first policy is to fill the truck by mixture of products from storage and products directly transferred from receiving door. In this policy filling the truck is a priority. However, in the second policy the truck filled only by products directly transferred from receiving door and the products in storage send by the last truck departing to the destination.

In this study we apply the approach of “accepting non-improving neighbours” to avoid local optima. To avoid cycles, the algorithm discards the neighbours that have been recently visited. We manage information of the solutions previously applied; This memory is called the Tabu list. Within any iteration of the Tabu, we update the tabu list memory. Indeed, we have to verify in any iteration that the created solution does not belong to the tabu list.

In this thesis, only information about the inbound changes is stored since no tabu is used when changing the outbound sequence. Specifically, we store the information of pairs of trucks that have been exchanged. In every beginning of our tabu search algorithm, we generate an initial table. This table contains three rows; first row has truck’s name data. Second row, has value of zero or one (tabu) for left movements of trucks and third row has value of zero or one for right movement of trucks. If the truck is exchanged with another truck in its left position, then this truck is not allowed to move again to right position for next exchanges. Accordingly, the truck with right movement is not allowed to move back again to the left of sequence. Cells with value of one, forbid the movement.

Suppose that we have an inbound sequence for two dock doors and five trailers as bellow; truck $\mathbf{S^{I}_{3a}}$ is exchanged with truck $\mathbf{S^{I}_{4a}}$. New sequence of N^{I} shows the result of this exchange.

$S^{I} = [S^{I}_{1a}, S^{I}_{2a}, S^{I}_{1d}, \mathbf{S^{I}_{3a}}, S^{I}_{2d}, \mathbf{S^{I}_{4a}}, S^{I}_{3d}, S^{I}_{5a}, S^{I}_{4d}, S^{I}_{5d}],$

$N^{I} = [S^{I}_{1a}, S^{I}_{2a}, S^{I}_{1d}, \mathbf{S^{I}_{4a}}, S^{I}_{2d}, \mathbf{S^{I}_{3a}}, S^{I}_{3d}, S^{I}_{5a}, S^{I}_{4d}, S^{I}_{5d}]$

Let us consider this new sequence of N^{I} is the best sequence with best value of neighborhood. This sequence is selected for the next iteration. The information of these exchanges has to be stored inside the tabu list.

In first sequence of S^{I}, truck $\mathbf{S^{I}_{3a}}$ is in left position of truck $\mathbf{S^{I}_{4a}}$**;** after exchanging this truck, $\mathbf{S^{I}_{3a}}$**,** is moved to right and truck, $\mathbf{S^{I}_{4a}}$, is moved to left position. Therefore, truck S^{I}_{3a} is not allowed to move back to left. Accordingly, truck S^{I}_{4a} is not allowed to move back to right.

The table of tabu is updated as bellow:

Truck	S^{I}_{3a}	S^{I}_{4a}
Left	1(Tabu)	0
Right	0	1(Tabu)

This table is completed in next iterations and other trucks will be added to the table; when the table reaches to the final size of tabu, first truck from the left, i.e., the earliest movement that has been tabu, is deleted and other trucks are shifted to the left of table.

Some papers use several short memories at a time; however in this project we restrict to a unique Tabu list that forbid some moves likely to lead us back to previously visited solutions. To manage the Tabu list, we may apply some efficient policies. We mentioned that the basic role of Tabu list is to prevent cycling; the size of Tabu list affects this role. The small size of Tabu list is not able to prevent cycling; conversely a Tabu list with too long size creates too many restrictions. It this project, we use a memory list with variable size for large instances of the problem to circumvent this difficulty. For small instances of the problem the size of Tabu list is achieved by bellow formulation;

n= number of inbound trailers;

Tabu size: $\sqrt{\frac{(n)(n-1)}{2}}$

To minimize transformation time of products for the problem of cross-docking, a good strategy is to transfer freights from receiving to shipping trucks directly. Conversely a suitable strategy is to have minimum transfer of products through storage. The main idea of the algorithm implemented for this research is taken as premises as above.

To construct a neighbor for current solution, the algorithm of Tabu is consist of two major stages; in every iteration, the problem is divided into subproblems by fixing a particular inbound (outbound) sequence and then finding the optimal outbound (inbound) sequence, respectively. In first step we fix the sequence of outbound and generate all neighbors for the sequence of inbound. The best neighbor among all neighbors of this inbound sequence is selected by evaluating the objective function. Then the best selected inbound sequence is fixed and we generate all outbound neighbors. Then the best receiving sequence and its associate shipping sequence among all these outbound neighbors is selected; if the movements are not in Tabu list then we accept the sequences as the best neighbour. This sequence will be our new current solution. In Figure 4-3, the procedure of our algorithm is shown;

In figure 4-3, the procedure of Tabu search for trailer scheduling in cross-docking problem is defined; Tabu search first initialize two sequences of inbound and outbound trucks that contains the information of arrival and departure of trucks(1). Then the value of maximum directly transfer of products is calculated for the initial sequences (2). This value is saved as the initial value and the best global value gained till now (3-4). We set the iteration number and empty the tabu list (5-6). While we do not reach the stopping criteria, maximum number of iteration, we continue (7-35). First, we fix the inbound sequence of trailers from the last iteration and find all the feasible outbound neighbors for this inbound sequence. If the outbound sequence in each neighborhood is feasible we calculate the maximum direct transfer of products and then find the best outbound sequence among all those neighbors (10-16). Then, the best outbound sequence from the last step is fixed and then we generate the neighbors of inbound sequences (17-18). For each neighbor of inbound sequence we verify its feasibility. If the sequence is not feasible we repair the sequence to be a feasible one (20-21).

We calculate the maximum directly transfer of products and save this value in a local value. The movement for generating the neighborhood is verified if is in Tabu list. If this local cost is better than the best value in whole neighborhood and if the movement is not in the tabu list we select that sequence as the best neighborhood. However, if the movement is in Tabu list and the local value is better than the best global value of the whole iterations, then we ignore the tabu list and we select that sequence as the best neighbour. The best global value, the best scheduling sequence of incoming and outgoing trailer for this iteration and Tabu list is updated (17-34). The result of best global value is returned after the stopping criteria.

4.4 Procedure Tabu Search

```
Initialize the feasible inbound and outbound sequences;
Calculate the objective function for initial sequences;
initVal ← value of objective function for the initial sequences;
BestGlobalVal ← initVal;
Iter ← 0; /* Iteration number */
TableTabu←Null
While not finished
        Iter ← Iter+1;
        BestNeigh ← -∞;
        STEP 1) Fix sequence of inbound trailers from last iteration
                Call function of neighborhood () for sequence of outbound trailers
                For each neighbor of the outbound sequences
                     Look if feasible then Calculate the objective function;
                     Else reject that outbound sequence
                End for;   //end for outbound
               Select the best sequence of outbound trailers among all neighbors
        STEP 2) Fix sequence of outbound trailers from last step
                Call function of neighborhood () for sequence of Inbound trailers
                For each neighbor of the inbound sequences
                     Look if feasible then Calculate the objective function;
                    Else repair that sequence to a feasible one
                     LocalVal← the value of objective function for each neighbour;
                    Check if movement is in Tabu list
                    If (LocalVal ≥ BestNeigh) then
                        If (Tabu and LocalVal > BestGlobalVal) or (not Tabu) then
                           BestNeigh← LocalVal;
                        End if;
                    End if;
                End for;   //end for outbound
                If (BestNeigh > BestGlobalVal) then
                      BestGlobalVal ← BestNeigh;
                End if;
                Save best sequence of inbound and outbound trailer for this iteration.
                Update the Tabu list;
End While;
Return BestGlobalVal;
```

Figure 4-3 - Procedure Tabu Search

4.5 Objective function

The objective of this thesis is to maximize the directly transporation of products for the sequences of inbound and outbound trucks. We apply the method which is proposed to obtain an optimal policy for the model of cross-docking (Maknoon, Baptiste et al. 2009).

In this approach, a network of possibilities is constructed. This network has N×N nodes. In this network, each node is shown by set (i,o) which (i) and (o) represent the order of incoming and outgoing trailers, respectively (these sequences contains the information of arrival and departure of trucks). Each node (i,o) represents the situation in which the trailers incoming i (arrival/departure) and outgoing o (arrival/departure) are at the dock doors. “Moreover, each node contains the information about the number of products in storage and in the current loading and unloading trailers for every passing path” (Maknoon, Baptiste et al. 2009).

As presented in Figure 4-4, from node (i,o) there are two possibilities of moves: move downward in sequence of incoming trailers (i+1,o) and moving forward and in sequence of outgoing trailers (i,o+1). When we move forward the network, (i,o+1) , the outgoing trailer of (o+1) depart the platform and it fill all by freights that unload from trailer (i) and storage. On the other hand, when we move to node (i+1,o), we fill the outgoing trailer with the freights from the incoming trailer (i+1) and we send the remaining products in trailer (i) to storage.

Each path from node (1,1) to node (N,N) is a feasible loading and unloading policy. In this network, a path with maximum number of directly transiting products is an optimal policy.

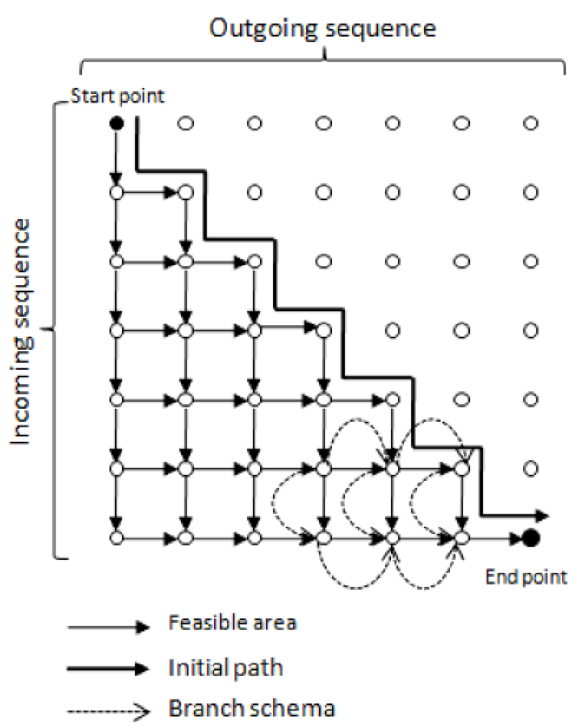

Figure 4-4 - Network of transition states - source:(Maknoon, Baptiste et al. 2009)

In this method, the algorithm constructs a network and determines the feasible paths. Some paths in the network are not feasible due to the following loading trucks constraints. The trailer could leave the platform when it is fully loaded. A node is infeasible if it does not belong to any feasible path. By applying this general rule, the feasible states are easily determined. Then, the algorithm performs a deep first search to find an initial path. The initial path contains a path with maximum loading of the trailers. After obtaining the initial path, the algorithm starts from node (N,N) and branches all paths. This procedure performs several forward and backward moves between the states in the network. The path with more directly transfers of products and trailer capacity is dominated. This procedure terminates when the algorithm reaches the node (1,1) (Maknoon, Baptiste et al. 2009). The value of maximum directly transfers of products of the best path is returned as the objective value of the sequences.

To evaluate the performance and efficiency of the metaheuristic algorithm of Tabu search, it is applied over a case study and the result compared with the existing methods results.

CHAPTER 5: CASE STUDY RESULTS

To analyze the solution approaches, we run the Tabu search algorithm for different problem instances; the instances are varied in number of doors, trucks and destinations;

The objective function of the experiment is maximizing the direct transfer of products and the procedures discussed in Chapter IV are implemented in C++, and the 31 problem instances of data are used to generate the results discussed in following sections. The result of Tabu search is compared with an iterative stochastic search embedded with a heuristic method to minimize the total sum of inventory holding cost.

Table 5-1, 5-2 and 5-3 show the results of implementing Tabu search algorithm for cross-docking with multiple-doors; in these tables, column of "Door#" indicates the number of doors for the layout of cross-dock. The column of "Truck#" shows the number of inbound trailers contain products for different destinations. The column of "Dest#" shows the number of destinations for freights. The shipping trailers carry the products for each destination. The results is showed for iteration number of 1000 and 10000; for each result the percentage of maximum possible direct transfer of products is calculated and presented in a separate column of "%max".

Table 5-1 summarizes the results of using cross-docking with 5 doors, while the truck number for 30, 45 and 60; and destinations products for 10, 15 and 20.

Table 5-1 - Results from Tabu search - 5 doors

#	Door#	Truck#	Dest#	Max Direct transfer	Tabu search – Direct Transfer			
					Iter: 1000	% max	Iter: 10000	% max
1	5	30	10	3000	2640	88%	2662	89%
2	5	30	15	3000	1904	63%	1950	65%
3	5	45	10	4500	3992	89%	4061	90%
4	5	45	15	4500	2945	65%	2975	66%
5	5	45	20	4500	2373	53%	2417	54%
6	5	60	10	6000	5396	90%	5417	90%
7	5	60	15	6000	3897	65%	4002	67%
8	5	60	20	6000	3116	52%	3208	53%
9	5	75	10	7500	6602	86%	6752	90%
10	5	75	15	7500	4890	64%	5023	67%
11	5	75	20	7500	3968	52%	4076	54%

Another way to represent the performance of the Tabu search is to examine the improvements for more doors. Table 5-2 shows the results of using cross-docking with 10 doors, while the truck number for 30, 45, 60 and 75; and destinations products for 20, 30 and 40.

Table 5-2 - Results of Tabu search - 10 doors

#	Door#	Truck#	Dest#	Max Direct transfer	Tabu search – Direct Transfer			
					Iter: 1000	% max	Iter: 10000	% max
1	10	30	20	3000	2705	90%	2714	90%
2	10	30	30	3000	1858	62%	1873	62%
3	10	45	20	4500	4083	91%	4095	91%
4	10	45	30	4500	3176	71%	3238	72%
5	10	45	40	4500	2552	57%	2569	57%
6	10	60	20	6000	5467	91%	5499	92%
7	10	60	30	6000	4042	67%	4059	68%
8	10	75	20	7500	6864	92%	6905	92%
9	10	75	30	7500	5204	69%	5260	70%
10	10	75	40	7500	4111	55%	4183	56%

Table 5-3 summarizes the results of using Tabu search algorithm for cross-docking with 15 doors, while the truck number for 30, 45, 60 and 75; and destinations products for 20, 30 and 40.

Table 5-3 - Results of Tabu search - 15 doors

#	Door#	Truck#	Dest#	Max Direct transfer	Tabu search – Direct Transfer			
					Iter: 1000	% max	Iter: 10000	% max
1	15	30	30	3000	2411	80%	2432	81%
2	15	45	20	4500	4416	98%	4418	98%
3	15	45	30	4500	4087	91%	4103	91%
4	15	45	40	4500	3263	73%	3265	73%
5	15	60	20	6000	5903	98%	5903	98%
6	15	60	30	6000	5372	90%	5381	90%
7	15	60	40	6000	4641	77%	4735	79%
8	15	75	20	7500	7408	99%	7408	99%
9	15	75	30	7500	6881	92%	6911	92%
10	15	75	40	7500	5645	75%	5698	76%

From these results, we find that our Tabu search algorithm for large problem instances can effectively reduce storage of products and improve the operations of cross-docks. In most results, running the problem with more iteration provides better results. In order to evaluate the effectiveness of Tabu search, we compare the algorithm of Tabu search with an iterative stochastic search embedded with a heuristic; Table 5-4, 5-5 and 5-6 show the result of this comparison.

Table 5-4 - Results of Tabu search compared with Iterative Stochastic search - 5 doors

#	Door#	Truck#	Dest#	Max Direct transfer	Tabu search – Direct Transfer	%Max Direct	Iterative stochastic	%Max Direct
1	5	30	10	3000	2640	88%	2693	89%
2	5	30	15	3000	1904	63%	1873	62%
3	5	45	10	4500	3992	89%	4053	90%
4	5	45	15	4500	2945	65%	3491	77%
5	5	45	20	4500	2373	53%	2295	51%
6	5	60	10	6000	5396	90%	5617	93%
7	5	60	15	6000	3897	65%	4783	79%
8	5	60	20	6000	3116	52%	3910	65%
9	5	75	10	7500	6602	86%	6965	92%
10	5	75	15	7500	4890	64%	6219	82%
11	5	75	20	7500	3968	52%	4707	62%

Table 5-5 - Results of Tabu search compared with Iterative Stochastic search - 10 doors

#	Door#	Truck#	Dest#	Max Direct transfer	Tabu search – Direct Transfer	%Max Direct	Iterative stochastic	%Max Direct
1	10	30	20	3000	2705	90%	2392	79%
2	10	30	30	3000	1858	62%	1747	58%
3	10	45	20	4500	4083	91%	3771	83%
4	10	45	30	4500	3176	71%	3013	66%
5	10	45	40	4500	2552	57%	2273	50%
6	10	60	20	6000	5467	91%	5319	88%
7	10	60	30	6000	4042	67%	3739	62%
8	10	75	20	7500	6864	92%	6626	88%
9	10	75	30	7500	5204	69%	5006	66%
10	10	75	40	7500	4111	55%	3809	50%

Table 5-6 - Results of Tabu search compared with Iterative Stochastic search - 15 doors

#	Door#	Truck#	Dest#	Max Direct transfer	Tabu search – Direct Transfer	%Max Direct	Iterative stochastic	%Max Direct
1	15	30	30	3000	2411	80%	2327	77%
2	15	45	20	4500	4416	98%	4402	97%
3	15	45	30	4500	4087	91%	3572	79%
4	15	45	40	4500	3263	73%	2960	65%
5	15	60	20	6000	5903	98%	5934	98%
6	15	60	30	6000	5372	90%	4884	81%
7	15	60	40	6000	4641	77%	4254	70%
8	15	75	20	7500	7408	99%	7386	98%
9	15	75	30	7500	6881	92%	6462	86%
10	15	75	40	7500	5645	75%	5242	69%

Table 5-4 shows that the Descent method, for cross-docking with 5 doors, gives better results when the number of trucks and destinations increase. But on the contrary, when number of doors increases, our Tabu search algorithm outperforms this method in most instances.

Tabu search algorithm performs very well in compared to descent method when the number of doors for a cross-dock layout increases. Table 5-5 and 5-6, show the result of this comparison. These tables indicate that Tabu search outperform descent search method in most cases with high amount of difference in objective function when number of doors are more than five.

In addition, our method performs well in scenarios that the sequence of incoming, outgoing, arrival and departure of trucks are not known in advance. This indicates the ability of our algorithm in the flexibility which can lead to higher efficiency. Our results show that the number of products stored in temporary could be reduces under our strategies. This is because the more accurate we establish coordination between the performance of inbound and outbound trucks and their arrival and departure schedules is, the more direct transfer of products will be for a cross-docking. Since more direct transfer of products provides less amount of storage.

In comparison to the descent method, Tabu search algorithm demands more time. This time varies for the number of trailers; increasing the number of trailers needs more amount of time to perform. Table 5-7, 5-8 and 5-9 show the calculation time in seconds of Tabu search for cross-docking with five, ten and fifteen doors; the processing time for the descent method is less than a second for each iteration even for large number of doors and trucks.

Table 5-7 - Algorithm time for 5 doors

#	Door#	Truck#	Dest#	Time (s) per iteration
1	5	30	10	0.07
2	5	30	15	0.07
3	5	45	10	0.13
4	5	45	15	0.17
5	5	45	20	0.24
6	5	60	10	0.28
7	5	60	15	0.33
8	5	60	20	0.32
9	5	75	10	0.68
10	5	75	15	0.63
11	5	75	20	0.61

Table 5-8 - Algorithm time for 10 doors

#	Door#	Truck#	Dest#	Time (s) per iteration
1	10	30	20	0.16
2	10	30	30	0.19
3	10	45	20	0.54
4	10	45	30	0.53
5	10	45	40	0.54
6	10	60	20	1.50
7	10	60	30	1.64
8	10	75	20	1.89
9	10	75	30	2.69
10	10	75	40	1.84

Table 5-9 - Algorithm time for 15 doors

#	Door#	Truck#	Dest#	Time (s) per iteration
1	15	30	30	0.45
2	15	45	20	1.35
3	15	45	30	1.84
4	15	45	40	1.75
5	15	60	20	1.81
6	15	60	30	1.54
7	15	60	40	3.74
8	15	75	20	2.66
9	15	75	30	2.63
10	15	75	40	2.63

In the recent past, researchers study the truck scheduling for cross-docking problem, but to date, no solutions for solving this problem for multiple-doors cross-docking with unknown sequence of trucks, have been developed. In this study, using the search algorithm of Tabu, we show the effectiveness of our algorithm on mitigating optimal inbound and outbound trucks schedule with their sequence of arrival and departure in multiple-doors cross-docks; In this study, the objective function of maximum direct transfer for products to travel through a cross-dock is formulated to test our method and evaluate the solutions in Tabu search. According to our results, our Tabu search algorithm can effectively improve the operation of multiple-doors cross-dock, including the reduction in product storage and cycle time. The effect of this algorithm could be noticeable for a supply chain management, including higher throughput, more reliable on-time delivery, and shorter transportation lead-time.

CHAPTER 6: SUMMARY, CONCLUSIONS AND FUTURE RESEARCH

In this research we focus on multiple-doors cross-dock because of its unique characteristics and including single door cross-dock problem. This research addresses to truck scheduling problem founds at cross-docking problem. This problem focuses of scheduling of incoming trailers from various suppliers and outgoing trailers for different end customers. It also considers the arrival and departure of trailers in every sequences; the following section summarizes this thesis and discuss some conclusions. The last part in this chapter makes recommendations for future research.

Detailed literature reviews on cross-docking and related subjects are provided and the truck scheduling problem in cross-docking is also studied in this project. In this thesis, we examine the metaheuristic of Tabu search and its different factors that may affect the performance of cross-docking. Tabu search algorithm is the most common approach among metaheuristics found in the literature reviewed to solve optimization problems. A Tabu search algorithm involves developing synchronized inbound and outbound sequences. This research provides a detailed description of how to construct an optimal combination of incoming and shipping scheduling and minimizing the storage of products; the Tabu search and its characteristics which affect the performance of algorithm is discussed. The neighborhood in the algorithm of Tabu search is explained and solutions are evaluated with an objective function of maximizing the direct transfer of freights. Using improved truck scheduling techniques offers the opportunity to reduce product travel distance, product storage and freight transfer time. The experiments indicate that Tabu search is effective is solving the problem of truck scheduling in multiple-doors and single cross-docking. The results also indicate that Tabu search offers optimal sequences for large problem instances.

This research makes the following contributions:

- Presents and tests a detailed Tabu search method for constructing optimal solutions;
- Develop a Tabu search algorithm with different methods of generating neighborhood for constructing synchronized inbound and outbound schedules;

- Provide a method to reduce the storage of products inside the warehouse and increase the total direct transfer of products from inbound trailers to shipping destinations;
- Evaluate Tabu search with other available heuristic.

This research developed Tabu search algorithm for multiple doors cross-docking with objective of maximizing the direct transfer of products. In the future, investigating the possibility of using other improvement techniques such as Genetic Algorithm, Particle Swarm Optimization (PSO), and Variable Neighbourhood search (VNS) and Ant Colony optimization (ACO) would be interesting.

Another area for future research is the performance measurement systems used to make improvements to the current system. The objective of the current research focuses increasing the amount of products transfer directly from incoming to shipping. This research attempts to decrease the amount of products transfer to temporary storage. Another area for future research would be to investigate other types of objective function in cross-docking problem (such as minimizing the makespan, total labor time and decreasing the amount of time shipments spend at the cross-dock). Examining these problems in a more integrated manner may also allow for further improvement. Traditional manufacturing measures of service may be used to measure the performance at the cross-dock, such as average through time, number of tardy shipments, or maximum lateness of shipments. Research that quantifies the economic impact of a customer service measure along with the labor costs at the cross-dock would be helpful in developing solutions that are most effective in improving the entire supply chain system (Brown 2003).

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