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A Review and Classification of Cross-Docking Concept

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Abstract: One of the strategies in the distribution field, which has shown a very high potential to control the costs of the product distribution in supply chain is the cross docking strategy and it functions as the mediator between the producers and retailers. These centers are able to increase the inventory turnover in the supply chain as well as decreasing the logistic costs. This paper represents an overview of the existing literature about this marvel concept and discusses about some different solved problems in this field. At the end a classification for this concept has been proposed, which categorizes the existing literature in two categories.

Keyword: Cross docking, Warehousing Strategy, Distribution strategy, Distribution Management, Logistics, Classification.

1 Introduction

Cross docking (CD), is a new strategy in logistics, which nowadays many companies use in many industries (Van Belle et al., 2012). A cross docking center or cross docking terminal is a center for distribution of goods. This type of distribution center is entirely devoted for the transshipment and distribution of the truck and container loads. Although there may be some differences between cross docking centers and the traditional distribution centers, but the more highlighted one is that there is no storage or at least there is a significant reduction for storage (Kinnear, 1997). This difference is due to the main idea behind the creation of these centers, which is transferring the incoming shipments straight to the outgoing or outbound vehicles without any storage in between (Van Belle et al., 2012). Boysen (2010) provides a definition for cross docking which is: “receiving product from a supplier or manufacturer for several end destinations and consolidating this product with other suppliers’ product for common final delivery destinations”. Shipments consolidation is the focus in this definition and the reason is for the transportation costs to achieve economies.

In addition, there is a definition provided by the Material Handling Industry of America (MHIA), which describes cross docking as “the process of moving merchandise from the receiving dock to shipping [dock] for shipping without placing it first into storage locations” (Van Belle et al., 2012).However, the focus of this definition is on transshipment and not stock holding. In order to achieve this goal there has to be an accurate synchronization for the inbound (incoming) and outbound (outgoing) vehicles. Therefore, cross docking can be defined as the consolidation of goods that come from different origins, but have the same destination, with the minimum handling and no or a little storage between the unloading and loading processes of the goods. If there should be any storage, many authors address the storage time of 24 hours, but it is very difficult to point out an exact limit for the storage time (Van Belle et al., 2012).

In this type of transshipment system, the trucks or containers (inbound trucks), which arrive at the center, are assigned to the receiving platforms. Then the inbound trucks are unloaded and the loads are checked, separated, categorized and moved to specific shipment platforms for immediate delivery by outbound trucks, according to pre-defined orders from retailers (Boysen, 2010). So, compared to the traditional stock systems, the storing and retrieving stages of the goods, which are the main elements of high costs, will be eliminated in cross docking systems. In other words, compared to the traditional warehousing, by synchronizing the inbound and outbound flows in cross docking systems, the storage cost in addition to the product retrieval costs will be considerably reduced (BolooriArabani et al, 2011c). Previous studies show that there can be many operation systems for material handing according to the shape of the cross docking center (Van Belle et al., 2012).

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2 Literature Review and Discussion

Reports from some companies such as Home Depo, Toyota, UPS, Wal-Mart, Kodack Co, Good Year GB, FedEX Freight, CostCo (Shakeri et al., 2008), post offices in Korea (Oh et al,. 2006) and some other companies have shown successful implementation of Cross docking in distribution systems. For instance, Wall-Mart (as pioneers in the application of cross docking systems) executives have considered using this system as the core competitive strategy since 1990. By reducing the distribution and inventory storage costs, this company could offer the "everyday low price" for which it is now famous (Bartholdi and Gue, 2004).

Li et al. (2004) try to make the operations of the cross docking center, which are unloading, sorting and loading processes, as efficient as possible. To achieve this goal, for a given schedule for the trucks, they consider the material handling inside the cross docking center. Once an inbound and outbound truck has been docked, all the operations that are mostly the handling operations, need to be assigned to the available resources, which are material handling devices and workers. This assignment has to be carried out in such a way that all the operations are accomplished and well-organized as possible. Mcwilliams et al. (2005) discuss about a problem on truck scheduling, in a mail distribution center. In this center, a conveyor belt system is used to move the goods. They used a simulation based optimization to solve the arising problem.

According to the reviews of the published studies on the subject of cross docking centers, these researches can be classified into two general categories:

The first category includes the studies, which probe the cross-cocking systems as a subset of supply chain. In this category, internal operations are not considered, but the focus is on the overall performance in the supply chain. In this approach, cross docking center acts as one element of the supply chain along with other components such as manufacturers, retailers and central warehouses.

In this category, Ross and Jayaraman (2008) consider a supply chain including potential retailers, series of cross docking centers and regional warehouses. The demand of each customer from each product type, which is supplied by the warehouses, is specified and it is the cross docking center that acts as an intermediate between the warehouses and the retailers. The capacity and the maximum number of each cross docking center and warehouses, the unit transportation cost from each warehouse to each cross docking center and from each cross docking center to each retailer are assumed as known values. The presented model with the purpose of minimizing the total cost, aims for the following:

- Identifying the cross docking centers and warehouses that should not be active
- Determining the number of products of each type, which should be transported from each warehouse to each cross docking center
- Determining the number of products of each type that should be transported from each cross docking center to each retailer

Moreover, the total cost of the supply chain that should be minimized includes the following:

- The fixed costs that are needed to keep the selected cross docking centers and warehouses active
- Product transportation cost from warehouses to the selected cross docking centers
- Product transportation cost from the selected cross docking centesr to the retailers

A linear programming model is presented to allocate the cross docking centers in the supply chain and it is solved by a combination of Simulated Annealing (SA) and Tabu Search (TS). In addition, details are provided to solve problems with large sizes and reach an approximate solution. Also Jayaraman, Gumus and Ratliff have presented similar problems on this area, but with different approaches (Ross and Jayaraman, 2008).

Larbi et al.(2011) proposed diversity of solution techniques in order to arrange a schedule for the outbound trailers in a cross docking terminal. The methods depend on the available information on the sequence of inbound trucks and the contents of their trailers. In their paper, they developed different solution techniques for the transshipment operations scheduling in a cross dock as well as contributing to the analysis of the importance and impact of information on the performance and efficiency of the operations in a cross docking facility. The numerical results show that the solution is not improved by the distant future information. They also demonstrate that it is better to make a series of decisions for a time period rather than a making a single decision upon receiving a new piece of information. Based on the objective to minimize the total costs of truck substitution and additional handling, a criteria for optimization has been considered by Larbi et al. (2011) that constitutes the minimization of operational costs, which is only one aspect of the cross docking. Other criteria that affect the levels of customer service, which are time dependent, are implicitly investigated in this study as well.

Dondo and Cerdá (2012) consider the pickup and delivery problem in a cross docking system, which is called the Vehicle Routing Problem with Cross docking (VRPCD). It involves accomplishing a set of requests for transportation by using a fleet of matching vehicles to fulfill the tasks of pickup and delivery. The problem originates from a process of consolidation. This process occurs at the cross dock and is intended for the incoming shipments. Dondo and Cerdá (2012) introduce a monolithic formulation for the VRPCD. Along with the truck scheduling at the cross docking center, the routes and schedules of pickup and delivery are determined by the outcome of this formulation. They included a set of constraint, mimicking the sweep algorithm, into the model, in order to derive a more efficient formulation. Near optimal solutions could be found by the resulting model, which was based on the sweep heuristic, for problems with large scale at very satisfactory and reasonable CPU times.

Tang and Tan (2010) studied a new application of a cross docking system in which two different, but not separate, methods have been put into practice. The first one is pre-distribution cross docking (Pre-C) in which the manufacturers bear the responsibility of distributing the products rather than the common warehousing areas and the second one is the operations of post-distribution cross docking (Post-C) where on the contrary with the Pre-c, usually the cross-docks are responsible for the products' distribution, not the manufacturers. In the recent approach, the distribution operations are is usually relegated to the cross-docks, which are closer to the customers. Both Pre-c and Post-c have their own advantages and disadvantages. Therefore, the decision makers face with a difficult process for selecting one over the other. Because, at the cross-docks, the Pre-c has lower operations cost than the Post-c and on the other hand, in the Pre-c, the quantity of transshipment is higher than the Post-c. The problem was analyzed and modeled by Tang and Yan (2010) to recognize the trade-off between these conditions. The conclusion and results showed that if in a cross-dock, operations costs or the inventory transshipment are considered, there are some factors that the applicability of the Post-c and the Pre-c are proportionate to them. These factors included the cost of shortage and inventory holding, the unit operations cost at the cross-dock, and the demand uncertainty.

An assignment problem was considered by Miao et al. (2009). In this problem, the objective is to simultaneously minimize two measures: the number of remaining unfulfilled shipments and the shipping cost. In addition, three main factors affect the problem that Miao et al. (2009) have considered in their study, the shipping time of trucks through ducks, the total capacity that is obtainable by the cross-dock, and the times of arrival and departure of each truck.

Arabani et al. (2010) investigates a cross docking scheduling problem. This problem is in a just-in-time environment in which the products delivery and pre-determined time schedules should conform. Therefore, the customers may not be satisfied by any soon or late deliveries. So in their study, in a multi-criteria scheduling problem, the two main criteria were considered as the tardiness and earliness. Also, considering penalties for any late or soon delivery of cargos, a penalty factor combines these criteria. Three meta-heuristics, Differential Evolution (DE), Genetic Algorithm (GA), and Particle Swarm Optimization (PSO) have been developed to solve this problem. When the quality of the solution is preferred, the Genetic Algorithm provides better solutions while superior solutions are reached by the Particle Swarm Optimization, if the preferred attribute is the lower elapsed time.

Chen et al. (2006) consider a network of a number of cross-docks in which the key role is played by the time windows of pickup and delivery operations. In their study, finding a minimum cost distribution plan is the objective. This plan is like a minimum cost multi commodity flow problem that is influenced by demands and supplies. Meanwhile, these demands and supplies look like deliveries and pickup with time windows in the related cross-dock.

Dondo et al. (2011) considers the cross docking system in a supply chain and tries to solve a vehicle routing problem which consists of satisfying customer demands at minimum total cost. In the supply chain management (SCM) and for the Vehicle Routing Problem with Cross Docking (VRPCD), they have developed a Mixed Integer Linear Programming (MILP) mathematical formulation. The locations of customer, warehouses and factories are the problem nodes. An event is defined as a vehicle stop, where some delivery and/or pickup operations will be accomplishment. These events are the problem nodes. For each location, a number of events are predefined. This number is a model parameter. This number needs to be at least equivalent to the correlated number of vehicle stops at the optimum solution. The objective of the proposed problem is to minimize the total cost of routing, which includes the costs of distance based and fixed costs. A second level objective is also adopted that is the travel time, which Dondo et al. (2011) tried to minimize in their VRPCD-SCM mathematical formulation.

Lee et al. (2006) consider a cross docking system in supply chain and tried to schedule the vehicle routing. They investigated a model that integrated cross docking with the two operations, pickup and delivery and developed a mathematical model to establish an optimal routing for vehicles. Since this is a NP-hard problem, Lee et al. (2006) also developed an algorithm based on a tabu search algorithm. They found near optimal solutions in 30 problems, which were randomly generated. The average percentage error of this near optimal solution was less than 4%. Their work can also be extended to the recycling and manufacturing processes.

Gumus& Bookbinder (2004) modeled location distribution networks that included cross docking terminals. Three multi-echelon networks were considered that each one of them generalized the preceding one. They formulated optimization models to minimize the total cost in these networks. Aside from optimally solving the problem, Gumus& Bookbinder (2004) also developed a tool for quantitative analysis of direct-shipment (shipments with no cross docks in between) decision. In their study, they considered a model with more than one product. In this model a cost effective sequence of products is determined for the shipments via cross docks (indirect shipment). Finally, this study obtains optimal solutions for 40 medium and larger scale models, in a multi origin network.

Jayaraman and Ross (2003) studied the application of simulated annealing in complex supply chain management problems. This paper descries a situation in which a supply chain employs two models. The manager of this supply chain has to determine the most proper cross docks and warehouses to operate while minimizing the cost of operations. These costs include the costs to supply products and costs of multiple shipment transportation from warehouses to cross docks, based on customer demands. The model to solve this problem is formulated as a mixed integer programming model. A practical and robust method is provided to solve a multi-echelon, multi product problem. The method was solved and optimal solution was obtained by using LINGO software for small problems. For medium and large scale problems, the model obtained near optimal solutions. In order to include patterns of stochastic demand, the model in this study can be revised.

In the second category, studies explore the issues and aspects of internal operations of the cross docking centers. Issues in various areas of design, planning, allocation and scheduling optimized operations, which are associated with products. In this category, we can mention Rohrer (1995), which is about how simulation, with optimized hardware configuration and software supervision (software controls) such as utilization of failure strategies, can assist the successful utilization of cross docking centers. In his paper, Rohrer has mentioned the hardware and software necessities of an efficient cross docking system, but he has not presented any practical example for his model.

In addition, Magableh et al. (2005) have developed a general model to present the internal operations of a cross docking center, specially the processing phase of inbound and outbound cargos. They have investigated the operational risk, which is related to each individual facility in the distribution network of a corporation, in a dynamic environment. In addition, this simulation model has been used to study the demand increment in a cross docking center. This model has integrally evaluated the simulation of problems such as allocation of product sources to the gates, flexible allocation of inbounding products to entrance gates and the outbound products to exit doors and the human resource requirements.

Bartholdi and Gue (2004) used simulation and investigated the best layout in a cross docking center. They have analyzed the most appropriate layout in design, such as E, H, T, U, L and I, considering the different conditions of a cross docking center. They believe that due to diverse reasons, product relocation in a cross docking center depends on work force, so they seek to evaluate the different layout forms with the goal of minimizing the product traveling distance. The results of this paper, on the foundation of three factors (number of gates, receiving to shipment rate and distribution of material flow) are as follows:

- With the increase in size of the centre, X, T and I shaped layouts are the best ones in the terms of manpower efficiency. Their studies show that for the maximum of 150 gates, *I* shaped layout, for 150 to 200 gates, *T* shaped layout and for more than 200 gates, *X* shaped layout are the best ones.
- According to the gates for receiving the cargos and density of product flow, *T* shaped layout may be more favorable than *I*, *X* and *T* shaped layouts.
- When the product flow is regular and the same, *T* and *X* shaped layouts will lead to more economy.
- *T* shaped layout is appropriate for the centers with a few gates, when the ratio of shipment gates to receiving gates is high.

In the area of scheduling problems and operational management in cross docking centers, one of the important issues is the matter of *allocation of receiving doors to the origins (usually the producers) that the products are to be sent from and shipping doors to the destinations that the cargos are to be sent to*. Tsui and Chang (1992) paper is one of the first studies to be published in the area of cross docking centers operations scheduling and is the first to study the allocation of the doors. In this paper a cross docking center with a rectangular shape, in which some of the doors are located on the larger side has been considered. The doors on one side are assigned to the inbounding trailers and the doors on the other side have been assigned to the outbound trailers. This paper has assumed that each door is assigned to only one destination and this assignment will remain the same until the transportation pattern changes (normally in monthly periods). However, it should be mentioned that in today's supply chain, the product distribution flow (such as Fast Moving Consumer Good: FMCG) and this assumption have not the necessary coordination with each other. Besides, the numbers of receiving and shipping doors are assumed more or equal to the number of vendors and destinations, which, in terms of operational and functional view, is not a proper assumption in cross docking centers. In this paper the problem of assigning inbound and outbound doors to vendors and cargos destinations, with the goal of minimizing the total traveling distance of the products between the receiving and shipping doors in these centers, has been proposed in the form of a zero-one nonlinear programming model. To solve the problem they developed a local optimum solution, which mainly depend on the initial value. They continued with a branch and bound algorithm, with a lower bound. The presented algorithm has been tested in terms of computational time for problems with various sizes of origins and destinations and the maximum of 11*12 and the sensitivity analysis for the relation between the lower bound and computational time has been carried out.

One of the other areas related to scheduling and operational management of cross docking centers is the problem of *scheduling the inbound and outbound containers*, which has an effective role in operations of a cross docking center. Yu and Eghbelu (2008) were the first ones to consider the problem of scheduling the inbound and outbound containers.

In the previous paper of Yu (2002) it is mentioned that depending on the strategies and different operational situations in cross docking centers, diverse operational models can be developed. According to 3 factors, which are number of available doors, transportation vehicles movement pattern inside and outside of the platforms and the possibility of temporary storage, he has categorized thirty two scenarios for cross docking centers and mentions that depending on operational characteristics, different operational optimization models should be developed. He refers to one of these scenarios as the base one for the others. In this basic scenario, the inbound containers enter the cross docking center and their consignments get unloaded at the receiving platforms, then get transferred to shipping platform by a conveyer and at the end get loaded onto the outbound containers and containers leave the centre. In another paper, Yu and Eghbelu (2008) use this scenario to determine the optimum scheduling model for inbound and outbound trailers. The assumptions in this model are:

- At zero time, all the inbound and outbound trailers are accessible.
- All the received products need to be sent out and there is no permission for the long term storage.
- The received and shipped unit numbers of a given product must be equal.
- For an inbound trailer, the sequence for unloading the products can be determined.
- For a given inbound truck, unloading only the necessary number of units of a given product type is permitted.
- It is allowed to only load one unit of a given product into the outbound trailer at a time. It means that it is prohibited to simultaneously load multiple units of a product from the temporary storage and the conveyor into an outbound trailer.
- For all the inbound and outbound trailers, the changeover time for trailers is the same.
- There is only one dock for receiving and one dock for shipping and they are apart from each other.
- An infinite capacity is assumed for the buffer of temporary storage.
- The following information is assumed to be known a priori:
  - ✓ The type and quantity of each product that is loaded into an inbound truck
  - ✓ The type and quantity of each product that needs to be loaded into an outbound truck
  - ✓ The times for load and unload the products.
  - ✓ The moving time of the unloaded products from the receiving dock to the shipping dock
  - ✓ The time for truck changeover

In accordance with these assumptions, a makespan is defined as the total operating time of the cross docking center. The total operating time starts from the moment when the first product of the first scheduled inbound truck is unloaded onto the receiving platform (receiving dock) to the moment when the last product of the last scheduled outbound truck is loaded from the shipping dock (shipping platform) (Yu and Eghbelu, 2008). The objectives of this model are to find the best sequence of inbound and outbound trucks in a way that the total operating time of the centre is minimized or in other words the throughput rate is maximized and to simultaneously assign the products from the inbound trucks to outbound trucks.

Three approaches have been used in this paper; first, a linear programming model to minimize the total operating time of the centre. Second, using the complete enumeration to generate all the possible sequences and third, employing a heuristic algorithm. Note that in the mathematical model it is presumed that the unloading time from a product from an inbounding truck and the time to load the product onto an outbound truck is the same for all products and it takes one unit of time for one unit of product. The mathematical model in this paper generates the definite answer for small and mid-size problems.

In the complete enumeration approach, all the possible sequences for the inbound and outbound trucks have been evaluated. In other words for *R* inbound trucks and *S* outbound trucks there are *R!*S!*possible sequences and the total operational cycle time is calculated for each one and the minimum one is selected. Yu and Eghbelu (2008) believe that this approach is beneficial in two ways; first, to show the efficiency of the other approaches, second, since this approach goes through every possible answer, the generated information can be used to determine the best and the worst solution to the problem.

But in the presented heuristic approach the main idea is to minimize the total number of products that go through the temporary storage. It includes two stages; in the first stage, according to the associate inbound truck selection strategy, the best associate inbound trucks are found for each unscheduled outbound truck. In the second stage, one of the unscheduled outbound trucks and the associate inbound trucks for the selected outbound truck is selected and scheduled. Since three strategies for the outbound trucks and three strategies for the inbound trucks are presented, so nine combinatorial strategies are tested and at the end, the combinatorial heuristic algorithm has provided some solutions that with 1.80% average deviation from the optimum clearly attests to the effectiveness of this approach (Yu and Eghbelu, 2008).

Boysen et al. (2010) have used another approach to solve the trucks scheduling problem. In this approach there is a receiving platform (receiving duck) to serve the shipping duck. The unloading and loading times are the same and a temporary storage area is provided for the products that the associated truck is not ready yet. In this paper, the *service slot* idea is introduced to schedule the trucks. A slot is defined as the time to unload an inbound container or the time to load an outbound one. In this paper, the mentioned problem is divided into two smaller problems. In each of these smaller problems, the sequence of inbound or outbound trucks is assumed as constant and the sequence for the other one is analyzed. Restricted dynamic programming and a heuristic approach based on *Priority Rule* are used to solve the model. However, Boysen et al. (2010) did not evaluate the efficiency of their solution for large and mid-size problems.

Chen and Lee (2009) modeled the trucks scheduling problem as a two machines *Flow Shop* problem. They consider a cross docking system with *n* inbound and *m* outbound tucks. They assume that due to space limitations only one inbound and one outbound truck can operate at a time. They point out that in this kind of situation, scheduling the unloading and loading operations for the inbound and outbound trucks affects the efficiency of the cross docking system and therefore, affects the efficiency of the whole supply chain. Considering the operations sequence, in this case, the job for the first machine is unloading and opening the inbound products and the job for the second machine is packaging and loading them. It is assumed that the second machine can not start working until the operations of the first machine is finished. Like other scheduling problems, the objective of this paper is also to minimize the makespan. As Chen and Lee continue in their study, they go through the aspects of problem optimization. They demonstrate that the nature of this problem is NP-hard. They believe that this problem is so much like the two machine flow shop scheduling problem, because if each destination needs only one product, the problem turns into a classic two machine flow shop, which can be solved by using Johnson algorithm (Chen and Lee, 2009). Using this particular algorithm, they generated some cases of the problem that can be solved like polynomial problems, then they have used a heuristic and a branch and bound algorithm to obtain the optimum solution. At the end, by using calculation tests in computers, they have shown that the branch and bound algorithm can solve the problems with almost 60 jobs in a reasonable time.

Song and Chen (2007) have developed the truck scheduling problem in a cross docking system in a flow shop framework to cover problems with numerous inbound doors. In this paper a two-stage optimization problem has been developed in which the first stage shows the inbound flow with different simultaneous trucks and the second stage demonstrates the outbound flow with one truck. On this basis, they have developed a mathematical model and used it to solve the small size problems. In addition, based on Johnson Algorithm, two heuristic approaches, with more efficiency, have been developed for mid-size and large size problems.

Shakeri et al. (2008) have developed a model with the objective of integrating two problems, which are scheduling the inbound/outbound trucks and assigning trucks to the doors of the cross docking centre. They used the Genetic Algorithm to solve the door assignment problem in a cross docking center, because optimizations of cross docking decision-making problems are usually very difficult. Their objective is to minimize the distance between unloading and loading the products (minimizing the total traveling distance). In their study, like Tsui and Chang (1992) , it is assumed that the number of receiving and shipping doors is more than vendors and retailers. In addition, similar to Vis and Roodbergen (2008) and Yu and Egbelu (Yu and Egbelu, 2008; Yu, 2002), due to the nature of cross docking centers, an area is considered for temporary storage of the products that have been unloaded, but the related truck is not ready at the shipping dock for the products to be loaded. One of the features of this model is that the number of the doors is not limited and each door can be a door for inbound or outbound trucks at the same time (the idea of virtual doors). Like what is mentioned in Chen and Lee (2009), here also the Combinatorial Multistage Flow Shop framework is used to model the operations of a cross docking centre like the trucks scheduling problem. In this model, each door is defined as a machine that the operations such as unloading, moving and loading the products are assigned to them as jobs. The unloading stage (First stage) consists of unloading the palettes out of the inbound trucks and moving them to the nearest temporary storage area to the respective shipping dock. The loading stage (second stage) consists of loading the palettes from the temporary storage area into the trucks. The loading stage is not possible until the precedence unloading stage is finished already. At the end the authors have presented a mathematical model to minimize the makespan. In this model it is assumed that the combination of assigning the products from the inbound trucks to the outbound trucks (mixing and matching problem) is pre-determined, because in most cases, determining the optimized assignment itself, is a very complex problem.

In another study, Vis and Roodbergen (2008) presented a problem, which in network problems is quite common. They considered a model as a minimum-cost flow problem. Have discussed about the temporary storage of the product units in a cross docking center. Their objective is to determine the optimal or at least the near optimal temporary storage area for the inbound products, which their related outbound truck is not ready, so they cannot be moved to the shipping docks. However, the main objective of their study is minimizing the total paced distance by the forklifts that convey the products from the inbound trucks to the storage area or from the storage area to the outgoing trucks. In their model, they have considered a row layout pattern in a rectangular area for products temporary storage. This area has some inbound and outbound doors, which are located at both sides of the storage area. Vis and Roodbergen (2008) assume that the assignment of each inbound/outbound truck to each inbound/outbound door, also the product types for each outbound truck is pre-determined. Considering the row layout for storage and the inbound and outbound door for each product, they seek the best row for every product. In addition, by using numerical examples, they have shown the efficiency of this method in design and operational phases of a cross docking system.

Boysen (2010) discuss a problem about the truck scheduling in the food industry, in which the inbound and outbound flows of products are synchronized at the zero inventory cross docking centers. In this paper different objectives such as tardiness, processing time and minimizing the flow time are considered and discussed and a proper dynamic programming, which is the exact approach, as well as simulated annealing approach, as a heuristic approach are presented. Then for the real world size problems of the developed simulated annealing, computational tests are used to indicate the appropriateness of this approach. In this paper, although the NP-hardness of the problem is considered to be very likely, the problem complexity still remains open.

In the study by Vahdani and Zandieh (2010) the inside operations of the warehouse are not considered. They consider that the sequence of the products is the same as their unloading sequence at the shipping docks. In addition, in front of the shipping dock, a temporary storage area is considered. In their work, in order to solve this problem, five meta-heuristics are developed. For this problem, the comparative study indicates that the best average result is obtained by the Variable Neighborhood Search (VNS).

A two-stage hybrid cross docking scheduling problem is proposed by Chen and Song (2009). In this problem, between the following and successive jobs, a precedence criterion needs to be satisfied. In their study, two different phases were used to deal with the model. For the small-scale problems, a mixed integer-programming model was addressed and solved by CPLEX, while four heuristics were proposed for the problems with medium and large scale, and via a given lower bound, they were compared with each other.

BolooriArabani et al. (2011b) considered a scheduling problem in cross docking. In this problem, inbound and outbound trucks are involved with one single receiving and one single shipping dock. The objective of this study was to minimize the makespan. To achieve this objective, five meta-heuristics, Genetic Algorithm, Tabu Search (TS), Differential Evolution (DE), Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO) were developed and they were compared with the heuristic that Yu and Egbelu (2008) proposed. The outcomes of the computational operations as well as the comparison results the five meta heuristics, especially Differential Evolution (DE), Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) can perform better than the heuristic, particularly, in problems with large scale.

BolooriArabani et al. (2011c) also investigated the cross docking and developed a multi-objective scheduling problem. The objectives were to minimize the lateness and the makespan. In fact, the scheduling problem is the method of scheduling and assigning the inbound and outbound trucks to meet and satisfy the objective functions. They expanded three multi-objective algorithms involving sub-opulation genetic algorithm-II (SPGA-II), strength pareto evolutionary algorithm-II (SPAE-II), and non-dominated sorting genetic algorithm-II (NSGA-II). Then, the parameters of these three algorithms were set for 10 different sets of problems. In addition, four measures were used to analyze the performance of each one of these algorithms. The results show that the SPGA-II and NSGA-II algorithms can relatively be overwhelmed by SPEA-II.

Liao et al. (2012) presented two hybrid differential evolution algorithms for the operations of a cross docking system to determine the optimal sequence for inbound and outbound trailers. The objective of their study is to minimize the makespan, which is the total operating time. They have also proposed a more efficient and practical operating method. According to the results of thirty problems, they demonstrated that better results were produced by Hybrid Differential Evolution-2 (HDE-2, one of the two proposed hybrid algorithms) than the best metaheuristic, which was Differential Evolution (DE). This metaheuristic was stated in a recent comparative study by BolooriArabani et al. (2011a) In the presented hybrid algorithms and for a chosen problem, the effects of key factors were examined. Their study is only appropriate to cross docking systems in which there are only one receiving and one shipping door.

3 Conclusion

This paper classifies cross docking problems into two categories: (1) cross docking problems when they are considered as a subset of a supply chain; (2) internal cross docking problems. During the recent years, a considerable number of papers have been published about cross docking. While some papers are concerned with cross docking in a general way such as its implementation or even its suitability, other papers deal with a particular type of cross docking problem in different levels such as operational, tactical or strategic. Some of the problems that published papers have tried to discuss are fairly common and there are many articles about the approaches to solve them. Some of these more popular problems are truck scheduling and dock door assignment problems. Even at the end of most of the papers, in which these common problems are considered, there are more areas of research to be extended for the future studies.

There are also some problems that have attracted much less attention to be studied. Some of these problems, which there are only a few published papers about are the layout design of the cross docks, the dimension, the arrangement and the shape of the internal facilities of a cross docks. Also the temporary storage for the cross docks is one of the areas of study that can be extended and more considered for the future studies, because with a good temporary storage strategy, internal cross docking operations such as traveling distances can be improved. In most of the papers, there are some assumptions and the real world limitations, which are usually neglected to simplify the considered problem.

Moreover, in real world, several problems need to be dealt with together. While some of the published papers consider more than one problem, most of them tackle just one problem. Since almost all the problems are interdependent, more improvements can be expected if they are dealt with together. So in the future studies a combination of cross docking problems and limitations can be an interesting area for research. Therefore, it is clear that cross docking can pose challenging and complex problems in different levels and since there are many uncertainties in practical problems, one shot optimizations are not enough and they need to be revised for better applications.

For the future, the author intends to develop a model for cross docking centers to choose their customers, which are producers and retailers, through an auction channel. This auction may consider quality, cost, reputation, etc. in its mechanism to choose the final producers (who will send their products to be distributed) and retailers (who will be chosen for the products to be sent to).

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