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JUST IN SEQUENCE SUPPLY WITH MULTILEVEL CROSS DOCKING

ÁGOTA BÁNYAI[1]

Abstract: The globalisation of the economy, which can be described by the reduction of transportation, communication and management costs, has changed the structure of logistics processes including purchasing, production, distribution and recycling. Production companies try to optimise their supply chain to reduce the logistics costs. One of the most powerful methods to simplify the supply chain is the cross docking. The aim of cross docking is to sort products intended for different production destinations or to combine products from different suppliers into transportation vehicles with the same destination. The cross docking can be used not only in the case of traditional, but also just in time or just in sequence supply. Within the frame of this paper, the author focuses on the advantages and disadvantages of cross docking concept of just in sequence supply. She describes a model of just in sequence supply with cross docking. By the aid of the described model, it is possible to describe the cost factors of the whole supply chain.
Keywords: cross docking, logistics, optimisation, purchasing, supply chain.

1. Introduction

The optimal design of supply chain processes required the cooperation of different knowledge: material handling technologies; transportation technologies; informatics and telecommunication; automation; marketing; mathematics and operation research; system theory; production technology; service technology; management and controlling. The optimal structure of supply chain processes makes it possible to suit the requirements of logistics: reduction of lead time; utilisation of capacities of logistics and technological resources; reduction of costs and improving of profit; raise the flexibility of processes; enhance of transparency; assure quality of products, services and processes; increase the value of internal and external recycling; reduction of emission; use of cleaner technologies; increase the satisfaction of users. The just in time production strategy is a useful tool to improve the return of investment by reducing inventory. The improvement of just in time philosophy leaded to the appearance of different just in time based sophisticated supply strategies called just in sequence. The just in sequence supply makes it possible to improve return of investment and return of assets with reducing inventory without loss the flexibility of the system. One possible way of realisation of just in time supply is the use of cross docking. The cross docking concept is especially usable in the case of just in time supply because cross docking concept is based on continuous communication of suppliers, production companies, distribution centres and end users, and in the case of just in time supply this continuous communication should be given. The design of cross docking processes and facilities takes effect the efficiency of the whole supply chain; therefore it is very important to optimise both of them.

[1] PhD University of Miskolc
H-3515 Miskolc-Egyetemváros, Hungary
altagota@uni-miskolc.hu

2. Literature overview

There are many possibilities to design material flow systems depending on the specification of different given processes [1]. The literature of cross docking related studies focus either on design of the physical layout of cross docking facilities or optimisation of cross docking processes. There are in the literature different basic studies summarising the state of the art of cross docking technologies of supply chain. The first main stream of these works describes the problem from the point of view integrated logistics processes [2]. The second main stream of works describes the state of the art of cross docking systems is based on problem types especially from the point of view operational problems [3]. The third main stream of the literature reviews focuses on the scheduling problems of cross docking processes and describes the classification of deterministic truck scheduling methods and tools [4]. The case studies of the literature include really complex systems, from which the most of them are third of fourth party logistics systems [5]. The fourth main stream compares the direct shipment with cross docking using cost functions including the costs of transportation, warehousing, loading and unloading operations [6].

Handling products in a cross docking facility are labour intensive because of the huge number of required materials handling operations: unload, load, sort, transfer, packaging, building of loading units, etc. The efficiency of these materials handling operations depends on the layout of cross docking facility. Models and methods can be used to minimize labour costs of transferring products through facility [7]. The scheduling of operations effect on the layout of cross docking. A common scheduling strategy of trailer scheduling makes it possible to reduce the queue of incoming trailers and assign them to doors to minimize the required material handling operations. There are models to support the design of cross docking facilities that exploit this queue reducing strategy [8].

The optimisation of cross docking networks is a very complex problem, especially from the point of view delivery and pick up time, warehouse capacities and materials handling costs [9]. In some cases, the just in time and just in sequence scheduling of cross docking operations can be modelled as machine scheduling problem and can be solved with different metaheuristics methods [10]. Some research works describe the cross docking problem as the design of service network design problem, where for the vehicle allocation direct services and material handling resources should be determined for each product demands. The vehicle allocation has to be designed in consideration of routing; capacities of transportation resources and time windows should be taken into consideration [11]. Some works focus on the difference between distribution centres and cross docking facilities: distribution centres are storing products for a long time, but in the case of cross docking facilities the products are going through them without storing for a long time; products are unloaded from the incoming trucks and almost immediately loaded onto the outgoing trucks. This problem can be described with a mixed integer programming with two-dimensional loading constraints [12].

There are different tools and methods, by the aid of which it is possible to optimise cross docking processes and facility layout: ant colony optimisation algorithm is used to solve an integer programming model of distribution networks including cross docking facilities [13]; metaheuristics to solve transhipment problems in a multiple door cross docking warehouse [14]; dynamic programming to schedule material handling operations in a cross docking facility [15]; optimisation of multi product green supply chain with harmony search algorithm [16]; polynomial time algorithm based heuristics to solve scheduling cross docking operations [17], discrete firefly algorithm to solve supplier selection to given order quantity [18]; harmony search algorithm to optimise multi-level supply chain [19], optimisation of large scale maintenance networks with evolutionary programming [20].

The just in sequence supply also has a wide literature. One main stream of these works focuses on the risk problems and availability of JIS supply. The real-time supply chain monitoring can help to detect supply problems in time [21]. When production companies define the delivery order and sequence for suppliers, the availability of components is in risk and reordering of production sequences is necessary [22]. It means that just in sequence supply reconfigure the production and assembly processes. The just in sequence supply influences not only the suppliers but also it makes it nece1ssary to reengineer the production and assembly processes [23].

3. Cross docking

Cross docking is a logistics strategy in which products are unloaded from incoming transportation vehicles and almost directly loaded onto outbound transportation vehicles or containers without longer storage time. The most important advantages of using cross docking facilities are the followings: reduced labour costs through reduction of inventories; reduced warehousing costs through the reduction of storage times and elimination of safety stocks; increased availability and reduced throughput time from suppliers to the customers. Cross docking is quite popular these days in the production and service companies, but amidst its popularity and above mentioned advantages there are some disadvantages in using cross docking: need for operation of an available and adequate transportation fleet; need up to date information and telecommunication system; the additional material handling in the cross docking facilities can lead to some unexpected product damages. The literature describe a huge number cross docking models, but to the author's knowledge there has been no research work on the field of design and modelling of multi level cross docking processes. The main result of this research work is the description of a mathematical model of multi-level cross docking process in the case of just in sequence supply.

The model of the multi level cross docking (Figure 1.) supply includes the following objects: cross docking facilities with receiving, sorting, shipping, sorting and storing function; suppliers, who can transport product to different levels of cross docking facilities; customers, who can be supplied from different levels of cross docking facilities:

$$\delta_{i,k} = \sum_{j=1}^{m} q_{i,j,k} \qquad \beta_i = \sum_{k=1}^{p} \sum_{j=1}^{m} q_{i,j,k}$$

We can define the required amount of products for each customer:

$$\alpha_i = \sum_{l=1}^{n} r_{i,l}$$

The first constraint of the optimisation problem is the following: the total amount of supplied products from suppliers to each cross docking facility must be equal to the amount required by each customer:

$$\alpha_i = \beta_i$$

Table 1

Explanations of variables

Variables	Explanations of the variables
$q_{i,j,k}$	Supplied amount of the i^{th} product, from the j^{th} supplier to the k^{th} cross docking facility.
$\delta_{i,k}$	Supplied amount of the i^{th} product to the k^{th} cross docking facility.
β_i	Supplied amount of the i^{th} product from each suppliers to each cross docking facility.
$r_{i,l}$	Requested amount of the i^{th} product by the j^{th} customer.
α_i	Total requested amount of the i^{th} product by each customer.

If the requested and supplied amount are equal, then the required amount of products cannot be transported into the customers, only if there is some safety stock in the cross docking facilities. If the requested amount is smaller than the supplied, then there is an extra stock in the cross docking facilities, which will cause extra warehousing costs.

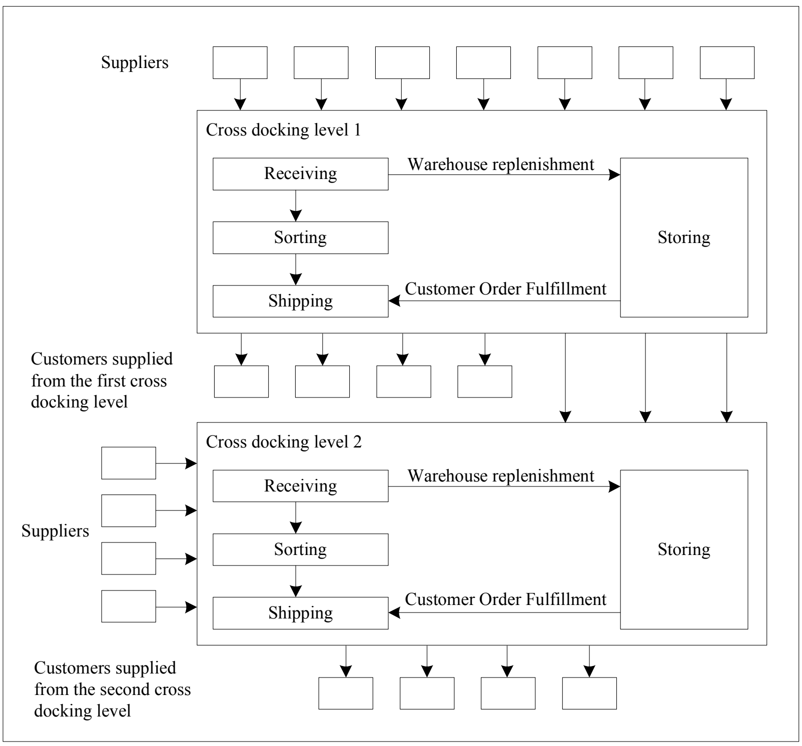

Figure 1. Multilevel cross docking supply

The objective function of the optimisation problem is the minimization of the total costs including the transportation costs of products from the suppliers to the different levels of cross docking facilities, among the cross docking facilities and from the cross docking facilities to the customers; the material handling costs in each level of cross docking; the storage costs of products in the case of warehouse replenishment; stock-out costs or shortage costs resulted by not late satisfied orders; storage costs of early satisfied orders by customers.

The transportation cost can be determined by the aid of transportation routes and capacities of transportation vehicles, depending on the positions of suppliers, cross docking facilities and customers:

$$C^{T} = \sum_{k=1}^{p} C^{T}_{S\to CD_k}(\Theta_k, \mathrm{R}^{S\to CD}) + \sum_{k=1}^{p}\sum_{x=1}^{p} C^{T}_{CD_k\to CD_x}\left(\Theta_{k,x}, \mathrm{R}^{CD}\right) + \sum_{k=1}^{p} C^{T}_{CD_k\to C}(\Theta_k, \mathrm{R}^{CD\to S})$$

Table 2

Explanations of variables of the transportation costs

Variables	Explanations of the variables
$C^{T}_{S\to CD_k}$	Transportation cost among suppliers and kth level cross docking facility.
$C^{T}_{CD_k\to CD_x}$	Transportation cost between kth level cross docking facility and xth level cross docking facility.
$C^{T}_{CD_k\to C}$	Transportation cost among kth level cross docking facility and customers.
Θ_k	Set of transported products in one transportation vehicle from suppliers to cross docking facility or from the cross docking facility to the customer; the aim of the optimization problem is to find the optimal sets for each time windows to assure the optimal scheduling of just in sequence demands of customers.
$\Theta_{k,x}$	Set of transported products in one transportation vehicle from cross docking facility to customers; this parameter depends on the location of cross docking facility and the customer.
R	Capacity of the transportation vehicle in the given relation.

The costs of material handling can be determined by the aid of the number of used cross docking facilities, depending on the following: amount of ith product transported from the suppliers to the cross docking facilities, amount of ith product transported among cross docking facilities and amount of ith product transported from the cross docking facilities directly to the customers, material handling capacities of loading and unloading machines of the cross docking facilities:

$$C^{MH} = \sum_{k=1}^{p}\sum_{i=1}^{s} C^{MH_{in}}_{CD_k}\left(\delta_{i,k}, \mathrm{R}^{MH}\right) + C^{MH_{out}}_{CD_k}\left(\vartheta_{i,k}, \mathrm{R}^{MH}\right) + C^{MH_{sorting}}_{CD_k}\left(\mu_{i,k}, \mathrm{R}^{MH}\right)$$

In the case of warehouse replenishment, we can calculate the costs of inventory depending on warehousing time and amount of products. The stock-out costs or shortage costs resulted by not late satisfied orders are the costs of customers. This can be realised in a form of a penalty to be paid by the suppliers or cross docking facility depending on the framework contract of supply. It is interesting, but early transports also cause extra costs because of the extra warehousing time of products before use by the customer's plant. These warehousing related costs can be calculated depending on the time window.

Table 3

Explanations of variables of the material handling costs

Variables	Explanations of the variables
$C_{CD_k}^{MH_{in}}$	Material handling cost related to receiving products in the kth level cross docking facility.
$C_{CD_k}^{MH_{out}}$	Material handling cost related to shipping of products from the kth level cross docking facility.
$C_{CD_k}^{MH_{sorting}}$	Material handling cost related to sorting of products to be shipped from the kth level cross docking facility.
$C_{CD_k}^{MH_{out}}$	Material handling cost related to shipping of products from the kth level cross docking facility.
$\vartheta_{i,k}$	Shipped amount of the ith product from the kth cross docking facility.
$\mu_{i,k}$	Sorted amount of the ith product in the kth cross docking facility.
R^{MH}	Material handling capacity of the loading and unloading machines.

The objective function of this problem can be summarised in the following form:

$$C = C^{MH} + C^{T} + C^{W_{CD}} + C^{SO} + C^{W\_CU}$$

The optimisation task is to choose the optimal time window and schedule the transport of products from the suppliers through the supply chain with more cross docking level. During the design of the supply chain difficulties are liable to occur because of the special conditions given by the just in sequence supply. It is not enough to take into consideration the time windows of the different request of customers but also to the sequences of the products should pay respect.

The results of the design process will be different supply routes. The first main stream of the solutions will include single level supply through only one cross docking facility with or without storage. The second main stream of material flow from suppliers to customers will be routed through more than one cross docking facility. The purposes of these multi level material flows are to optimise the transportation costs through increasing the capacity utilisation.

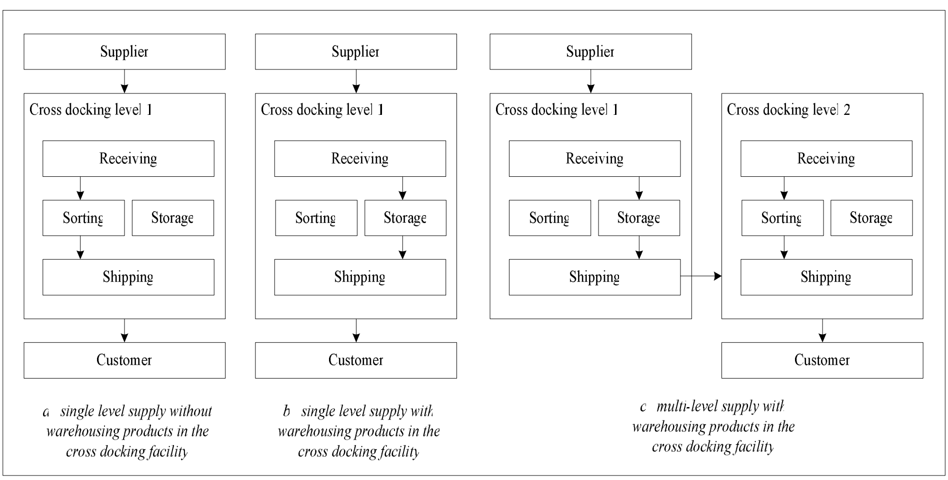

Figure 2. Different supply solution of a supply chain with multi level cross docking facility

The just in sequence supply require the exact scheduling of transportation. To fulfil this requirement, the supply chain must be controlled by an integrated enterprise resource planning system. Up-to-date ERP systems makes it possible to take into consideration the above mentioned interests of suppliers, cross docking facilities, transport companies and customers. The optimisation algorithm should take into consideration the conflicts of interest and decrease them to assure the maximal satisfaction of all partners of the supply chain.

4. Further research directions

Here, the description of the scheduling of transportation is ignored. This simplified representation is near to the reality, but the measure of how is it possible to optimise the scheduling of the purchasing process to refine the model and make it suitable for the optimisation of the whole supply chain including all functional processes will be useful.

5. Summary

The aim of this research work was the description of a multi level supply chain with cross docking facilities in the case of just in sequence supply. The model of this supply chain includes the suppliers, who can transport their products to different levels of the cross docking facilities. The objective function of the optimisation of this supply chain is a cost function including the costs of transportation, material handling and warehousing. By the aid of the mentioned cost function, it is possible to make a large scale design of the supply scheduling.

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