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Theoretical Concepts and Mathematical Models of Cross-Docking Logistics in Supply Chain Management

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Abstract

With the advancement of emerging smart technologies, it is being a big challenge to interlink people and society with the production systems. Therefore, synchronization of all partners along the supply chain logistics system is a crucial and essential part of the business operations. A cross-dock is a consolidation point in a distribution network, where multiple smaller shipments can be merged to full truck loads in order to realize economies in transportation. In this paper, a brief literature of cross-docking approach for supply chain logistics problem is presented. On describing the problem theoretically together with figures, a mathematical model of cross-docking logistics problem is formulated as truck sequencing problem to minimize the makespan. The lower bound and its complexity are also discussed concisely. The whole problem is decomposed into two sub-problems as inbound and outbound parts as a solution strategy for truck sequencing problem.

Keywords: Just-in-time, Supply chain, Cross-docking, Logistics, Decomposition

Introduction

Today's business challenge for production management lies in providing the

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customers with products of excellent quality, at lowest cost and in-time delivery performance in the pursuit of customer satisfaction, and staying ahead of competitors through market creation activities. The production technology principle in Japan that contributed to the world in the latter half of the 20th century was the Japanese-style production system known as Toyota Production System. This system was enhanced by the quality management technology principle generally referred as just-in-time (JIT) production system. To realize the best quality production and JIT distribution for the customer in a rapidly changing technical environment, it is essential to create a cross-docking environment throughout the whole supply chain system that is capable to address the diversified demands. Cross-docking approach is the movement of products directly from receiving dock to shipping dock with minimum dwell time in between. By arranging for immediate cross-docking of incoming products, retailers are able to reduce transit time for their incoming products. The effective application of cross-docking technique requires good information systems and close synchronization of all inbound and outbound shipments.

Since the introduction of the term supply chain management (Oliver & Webber, 1982), it has received ever-growing interest both in the literature as well as from industrial practice. A supply chain system is the network of organizations, people, activities, information and resources involved in the physical flow of products from initial suppliers to final customers, which consists of three major sub-systems: Procurement, Production, and Distribution. Several research studies have been performed in production and distribution networks independently without considering the interaction between activities in different sub-systems (Christopher, 1998; Ghiani, 2004). However, many decisions in production and distribution sub-systems need to be addressed simultaneously while minimizing the costs associated with production, inventory, warehousing and transportation. The mutual coordination/collaboration among independent firms (*viz.*, raw-material suppliers, manufacturers, distributors and retailers) is the crux to attain the flexibility required to enable them in the progressive improvement of logistics processes in response of rapidly changing market conditions. Poor coordination among the chain members can cause dysfunctional operational performance, such as higher inventory and transportation costs, longer delivery times, higher levels of loss or damage and lower customer service

(Lee et al., 1997). The effective operation of transportation systems determines the efficiency of moving products, which is a crucial part in overall supply chain logistics.

Literature Review

Generating the optimal production schedule for an assembly line to balance the overall supply chain under a variety of practical constraints is a difficult task. Many companies are attempting to make their production system more flexible or adaptable to change in order to respond the varying customer demands. As mentioned above, one of the most significant concepts in business management in past decades has been JIT production system originating from Toyota in Japan (Dhamala et al. 2012; Thapa & Dhamala, 2009), which is a philosophy as much as a technique based upon the idea that no activity should take place until there is a need for it, that is, no products should be made or ordered until there is a requirement for them. Thus, JIT is a pull production concept where demand pulls goods towards the market. In fact, JIT production logistics forms a specific part of the supply chain, which deals with the planning and control of materials and information flows throughout the production and distribution supply chains of manufacturing companies with the mission to get the right materials to the right place at the right time in perfect quality at the lowest possible costs (Ghiani, 2004; Thapa & Dhamala, 2009). The JIT logistics is performed to optimize some sort of given performance measures, for example minimizing total operating costs and to satisfy a given set of constraints, for example budget constraints. Moreover, it is a mobility concept relating with tangible as well as intangible assets (Beamon, 1998; Thapa et al., 2010), and hence it is the true realization of JIT production and delivery systems: a management philosophy which uses a set of integrated activities to achieve manufacturing flexibility with minimum shortages and inventories. The extended scenario of the supply chain network is shown in Fig.1 in terms of inbound and outbound logistics (Thapa et al., 2014; Thapa, 2015).

One of the most important factors in implementing supply chain management (SCM) is to efficiently control the physical flow of the materials. Due to its importance, many companies are trying to develop efficient methods to increase customer satisfaction and reduce costs. In various methods, cross-docking is considered as a good method to reduce inventory and improve responsiveness to various customer demands.

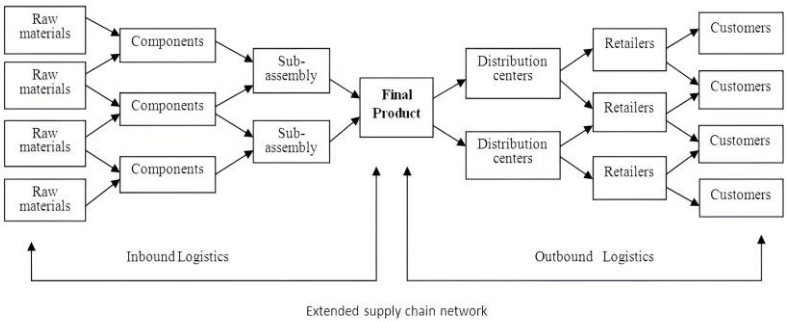

Figure 1 Supply chain synchronization in production and distribution system

However, previous studies have dealt mostly with the conceptual advantages of cross-docking or actual issues from the strategic viewpoint. It is also necessary to consider cross-docking from an operational viewpoint in order to find the optimal vehicle routing schedule. The cross-docking strategy is formally defined as a process where products are received in a distribution center occasionally merged with other products going to the same destination, then shipped at the earliest opportunity, without putting away, storing and picking, as shown in Figure 2.

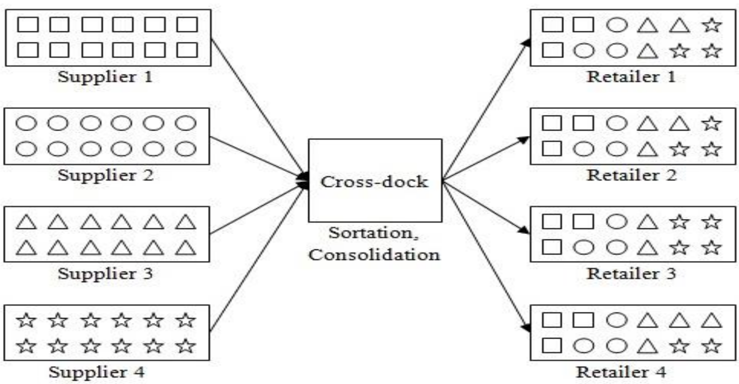

Figure 2 Freight consolidation at the transfer terminal (Cross-dock scenario)

The advantages of cross-docking include little or no inventory, low handling costs, low space requirement, centralized processing and low transportation costs. Buffa (1986) showed that logistics cost could be reduced by integrating the inbound and outbound vehicles in the distribution system. A framework for understanding and designing cross-docking systems is provided and techniques are discussed to improve the overall efficiency of the logistics operations (Uday & Viswanathan, 2000). The role of information logistics in supply chain production process has been studied in (Thapa et al., 2010; Thapa et al., 2014).

According to Christopher (1998), a supply chain (SC) ". . . is a network of organizations that are involved, through upstream and downstream linkages in the different processes and activities that produce value in the form of products and services in the hand of the ultimate consumer" (p. 25). This definition stresses that all the activities along with SC should be designed according to the needs of the customers to be served. Consequently, the final consumer is an integral part of the SC at the best. The main focus is on the order fulfillment processes and corresponding materials, financial and information flows. If the organizational units belong to one single enterprise, an intra-organizational SC is given, where hierarchical coordination is possible and prevailing. While hierarchical coordination in globally operating enterprises is already a demanding task, the real challenge arises in an inter-organizational SC where hierarchical coordination is no longer possible. Although there is a coherent view of what a SC represents, there are numerous definitions of SCM (Otto & Kotzab, 1999). Extracting the essence of existing definitions, SCM is the task of integrating organizational units along a SC and coordinating materials, information and financial flows in order to fulfill final customer demands with the aim of improving competitiveness of the SC as a whole. This is best visualized by the house of SCM and logistics in Fig. 3 (Stadtler, 2002; Stadtler 2005).

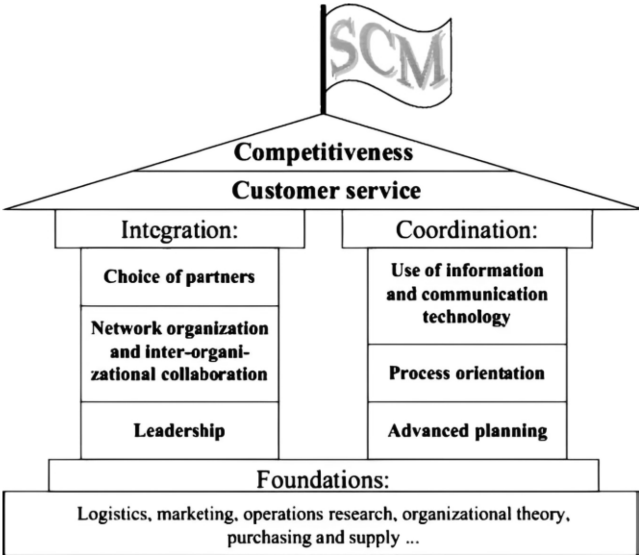

Figure 3 House of SCM and logistics

Only very few research papers deal with the short-term scheduling problems arising during the daily operations of cross-docking terminals. Li et al. (2004) considered material handling inside the terminal for a given truck schedule. They modeled this problem as a machine scheduling problem and presented a meta-heuristic suited for its solution. Once a set of inbound and outbound trucks is docked, jobs consisting of products to be handled have to be assigned to resources, *i.e.,* workers and means of conveyance like fork-lifts, in such a way that efficient unloading, sorting and loading operations render possible. The cross-docking problem is dealt as the truck scheduling problem in (McWilliams, 2005; Yu & Egbelu, 2008), wherein they investigated detailed truck scheduling problems dedicated to quite special cross-dock settings, so that their models cannot serve as a basic reference model, which might be generalized to other cross dock-settings. The transportation of goods within the dock is modeled as a detailed scheduling problem, for which they presented a priority rule-based start heuristic.

Boysen et al. (2010) presented a stylized “one inbound door serves one outbound door” setting in order to generate fundamental insights to the underlying real-world problem structure. Exact handling times for inbound trailers depend on the exact packing of goods and the sequence in which they can be obtained, whereas those for outbound trailers have to account for load stability and the sequence in which customers are served. Moreover, the determination of transportation times between doors results to a complex optimization problem in itself. Individual handling times are merged for products to service slots to which inbound and outbound trucks are assigned (Boysen, 2010). A slot comprises the time required for completely unloading an inbound truck and completely loading an outbound truck. Handling times in between dock doors are considered by a delay (measured in number of slots) which covers the time span until incoming products are available at an outbound door. This aggregate view seems to be sufficient to model the truck scheduling problem, especially in a medium-term horizon, when arrival and departure times of trucks are to be negotiated with logistics companies. By a simultaneous scheduling of inbound and outbound trucks, incoming flows of products are harmonized with outbound flows, so that a JIT supply of products, and thus, a reduced turnover time is enabled. For the detail study of production planning problems in both production and distribution parts with their mathematical formulations, readers are referred to visit some existing literatures (Boysen et al., 2010; Thapa & Dhamala, 2009; Thapa & Silvestrov, 2015; Thapa, 2015; Thapa, 2014).

Problem Description

The production logistics problem is considered as truck sequencing problem in this paper. The notational convention is described as follows: Let I and O be the sets of inbound and outbound trucks at the single receiving door and the single shipping door respectively of the cross-docking terminal. Each inbound truck is loaded with units of different products $p \in P$. Suppose $a_{\alpha p}$ be the number of units of product type *p* arriving in an inbound truck α and $b_{\beta p}$ be the number of product type *p* to be loaded onto outbound truck β. All product units are completely unloaded within a service slot (period) *t* to which the respective inbound truck is assigned, so that all handling operations (*e.g.,* docking, unloading and undocking) required to process the truck are executed within this time span *e.g.,* an hour or two. Moreover, all inbound trucks are assumed to be available for processing at the beginning of the planning horizon, so that a static problem with identical arrival dates of inbound trucks is considered.

The assumption of equally long service times can be seen as a reasonable approximation of reality, whenever vehicle capacities and the number of products per vehicle do not strongly differ. Once unloaded, the delivered products have to undergo several subsequent operations before they are available for being loaded onto the outbound trucks at the shipping door. These operations include recording of any product unit in the information system, examining the product correctness and quality, collecting, sorting, rearranging and packing to recombine products from different inbound trucks to form the load of a certain outbound truck. Finally, the products have to be transported to the shipping door, where they wait in an intermediate buffer of sufficient size until they are needed. This variety of tasks from recording to transporting is assumed to last a fixed movement time m irrespective of the truck load actually processed. Then, all products arriving in a slot t are available for loading at the shipping dock not before the slot $\mathrm{t} + \mathrm{m}$ if the movement process can be started for any unloaded unit immediately, *e.g.* when applying a conveyor belt system. If the movement starts not before the complete inbound truck has been unloaded completely (*e.g.* a worker stacks all units behind the receiving door before moving them), the units are first available at slot $\mathrm{t} + \mathrm{m} + 1$. However, the displacement *m* or $\mathrm{m} + 1$ respectively, can be ignored (set to zero) when modeling and solving the problem, because, after having determined a solution, an appropriate re-indexing of slots outbound trucks is assigned to (by adding displacement) allows the exact determination of the outbound schedule. Similarly, to constant unloading times, it is assumed that the movement time m is independent of the inbound truck and the loaded products, because handling full truck loads, which may always consist of almost the same number of product units, should take very similar times (Boysen et al., 2010; Thapa et al., 2010; Yu & Egbelu, 2008). This assumption is realistic especially within an aggregated medium-term scheduling approach as proposed.

At the shipping door, the set O of outbound trucks is to be loaded, each $\beta \in O$ with a predetermined number of units $b_{\beta p}$ of the different products $p \in P$. Again, it is assumed that all handling operations per truck are completed within a single slot. An outbound truck can be assigned to a slot *t* not before enough stock has accumulated in the intermediate buffer to serve all demanded product units of the truck. As only temporary stock is allowed (or desired) within a cross dock, it is assumed that temporary stock is empty before the first inbound truck arrives and is emptied out again after the last outbound truck was served. Thus, within our model the following equality holds: $\sum_{\alpha \in I} a_{\alpha p} = \sum_{\beta \in O} b_{\beta p}, \forall\, p \in P$. The simplifying assumptions applied to our base model are summarized as follows (Boysen et al., 2010):

i. Inbound trucks are processed at a single receiving door of the terminal, which serves a single shipping door for outbound trucks. Both doors are distinct.
ii. Processing trucks (*i.e*., all loading and unloading operations) takes same amount of time.
iii. No predefined restrictions on truck assignments to slots, *e.g.* release or due dates, exist.
iv. The input data is known in advance with certainty (static deterministic problem).
v. The movement time of products across the dock is a given constant and can be ignored.
vi. The sum of units delivered by inbound trucks equals the sum of units consumed by outbound trucks for any product *p* (only intermediate stock).
vii. Intermediate buffer for intermediate stock is not limited in size.

Problem Formulation

The following notations are set to formulate the cross-docking supply chain logistics problem:
I = Set of inbound trucks (indexed by α); O = Set of outbound trucks (indexed by β)
P = set of products (indexed by p); T = total number of time slots (indexed by *t*)
$a_{\alpha p}$= quantity of p arriving in truck α; $b_{\beta p}$ = quantity of p to be loaded in truck β

$$x_{\alpha t} = 1, \text{ if inbound truck } \alpha \text{ is assigned to slot } t$$
$$0, \text{ if otherwise}$$

$$y_{\beta t} = 1, \text{ if outbound truck } \beta \text{ is assigned to slot } t$$
$$0, \text{ if otherwise}$$

As a direct result of the simplifying assumptions, the inbound and outbound schedule can be readily derived by the sequence of inbound and outbound trucks, so that the problem reduces to a truck sequencing problem (TRSP). The objective is to sequence the trucks in such a way that the operation time, called makespan, is minimized which comprises the time span starting from the first slot to which an inbound truck is assigned and lasts until the final slot in which an outbound truck is processed. With above notations, the TRSP problem is formulated as follows (Boysen et al., 2010; Thapa, 2015):

Minimize

$$M = \sum_{t=1}^{T} \left| t\, x_{\alpha t} - t\, y_{\beta t} \right|, \quad \forall \alpha \in I \;\; and \;\; \beta \in O \tag{1}$$

subject to

$$\sum_{t=1}^{T} x_{\alpha t} = 1, \quad \forall \alpha \in I \tag{2}$$

$$\sum_{\alpha \in I} x_{\alpha t} \le 1, \quad \forall t = 1, \; 2, \ldots, \; T \tag{3}$$

$$\sum_{t=1}^{T} y_{\beta t} = 1, \quad \forall \beta \in O \tag{4}$$

$$\sum_{\beta \in O} y_{\beta t} \le 1, \quad \forall t = 1, 2, \ldots, T \tag{5}$$

$$\sum_{\tau=1}^{t} \sum_{\alpha \in I} x_{\alpha \tau} \,.\, a_{\alpha p} \ge \sum_{\tau=1}^{t} \sum_{\beta \in O} y_{\beta \tau} \,.\, b_{\beta p}, \;\; \forall t = 1, \ldots, T; \; p \in P \tag{6}$$

$$x_{\alpha t} \in \{0, \; 1\} \quad \forall \alpha \in I; \;\; t = 1, \ldots, T \tag{7}$$

$$y_{\beta t} \in \{0, \; 1\}, \quad \beta \in O; \, t = 1, \ldots, T \tag{8}$$

The objective (1) minimizes the sum of the absolute difference of operation times of outbound trucks β and inbound trucks α. The constraint (2) ensures that each inbound truck is processed in exactly one slot, whereas constraints (3) enforces that in each slot at most one inbound truck can be assigned. In analogy, these two conditions also hold for outbound trucks by constraints (4) and (5). Constraints (6) ensure that an outbound truck can only be assigned to a slot t whenever all required products are available (delivered by preceding inbound trucks yet not consumed by preceding outbound trucks) to satisfy the demand for product units of each type p. Therefore, the available stock accumulated by all inbound trucks assigned to slots $\tau = 1, \ldots, t$ has to exceed the total demand for product units of outbound trucks scheduled up to the actual slot t (note that this will actually be slot $t + m$ or even $t + m + 1$ when realizing the schedule). The constraints (7) and (8) represent the binary variables for inbound and outbound trucks in order.

As the makespan is to be minimized, the number of service slots actually required is unknown prior to the solution of the model. Thus, within the model the number of slots T is to be initialized with some upper bound B on the makespan: $T = B$. One simple upper bound is given by the equation (9):

$$B = |I| + |O| - 1 \quad (9)$$

This bound is based on the consideration that in the worst case the first outbound truck scheduled requires a product loaded on the last inbound truck scheduled. Consequently, all outbound trucks have to wait until all inbound trucks are unloaded. To tighten the model formulation, *e.g.* when using a generic MIP-solver, the following property of optimal inbound schedules can be utilized (Boysen et al., 2010), by which number of variables and constraints can be reduced:

Left-shift property: It is sufficient to reduce the set of time slots considered for an assignment of inbound trucks to the first $|I|$ slots. This is obviously correct, because if there exists an optimal solution, where inbound trucks are not assigned to slots $t = 1, \ldots, |I|$ in direct succession, then trucks can be brought forward (without altering the sequence) and the objective value remains the same. Thus, there is always at least one optimal solution where inbound trucks are assigned to the first $|I|$ slots.

As alterations are truly straight forward, an abstain from explicitly recording them is done. Furthermore, the TRSP is NP-hard in the strong sense (Boysen et al., 2010).

Lower Bounds

The first simple lower bound B_1 reverses the logic of our upper bound. In the best case, each outbound truck has a direct counterpart among the inbound trucks, so that inbound and outbound trucks can be scheduled successively without any delay:

$$B_1 = \max \{|I|; |O|\} \quad (10)$$

For the computation of another lower bound B_2, the overall problem is decomposed in $|P|$ sub-problems by cutting off the truck coherency of products. For each product the minimum makespan is deduced by separately scheduling inbound and outbound trucks. Thus, it is relaxed that for each product the same truck sequence has to be maintained.

The optimal solution for each sub-problem can be determined by considering the following simple rules, which share some similarities with those of the famous Johnson algorithm for the two-machine flow shop scheduling problem (Johnson, 1954):

- Sort the set I of inbound trucks with respect to descending loads $a_{\alpha p}$ of the product p actually considered. This leads to a sequence vector π^p with elements π^p_α, $(\alpha = 1,\ldots,|I|)$. The schedule for this sequence vector is readily available because of the left-shift property: Inbound trucks are scheduled according to sequencing vector π^p in direct succession starting with slot $t = 1$.
- Sort the set O of outbound trucks with respect to ascending loads $b_{\alpha p}$ of the actual product p. This sequence is stored in the vector μ^p with elements μ^p_β, $(\beta = 1, 2, \ldots, |O|)$. The resulting slots $s_{p\beta}$ can be computed by assigning, in each case, the first feasible slot number t according to:

$$s_{\beta p} = \min\left\{ t = s_{\beta-1p} + 1, \ldots, T: \sum_{\tau=1}^{\min\{|I|,\ t\}} a^p_{\pi\tau}\, p \geq \sum_{\tau=1}^{\beta} b^p_{\mu\tau} p, \forall\ \beta \in O; p \in P \right\} \quad (11)$$

To initialize the recursive formulae (11), a slot μ^p_β has to be initialized with slot number β. The lower bound B_2 then simply amounts to the maximum makespan over all products

$$B_2 = max_{p \in P} \{s_{|O|p}\} \quad (12)$$

The lower bound B_2 has a runtime complexity of $O(n\,log\,n)$, where $n = max\{|I|; |O|\}$, due to the sorting operations, which is considerably higher than that of B_1. However, it can be shown that both bounds in any case lead to the same result (Boysen et al., 2010).

Decomposition: A Solution Strategy for TRSP

The overall TRSP is decomposed into two sub-problems, namely inbound TRSP and outbound TRSP, briefly written as IBD-TRSP and OBD-TRSP respectively. It is divided into sub-problems by fixing a particular inbound (outbound) sequence and then finding the optimal outbound (inbound) sequence, respectively. In the following, the considered sub-problems are formalized and identified a strong structural relationship that can be exploited in the solution procedure. In the first problem, let us assume that there is a fixed sequence π of inbound trucks given, so that the inbound schedule can immediately be deduced by assigning the trucks in the respective order to the first $|I|$ slots (see left-shift property). Thus, the number A_{tp} of the product units available for outbound trucks is known in advance for each slot t:

$A_{tp} = \sum_{\tau=1}^{min\{|I|;t\}} a_{\pi_\tau} p, \ \forall p \in P; t = 1, 2, \ldots, T$ With the available stock (cumulated input) on hand, the problem OBD-TRSP reduces to objective function (1) subject to constraints (4), (5), (8) and (13):

$$A_{tp} \geq \sum_{\tau=1}^{t} \sum_{\beta \in O} y_{\beta\tau} \,.\, b_{\beta p}, \qquad \forall t = 1, 2, \ . \ . \ . \ , T; p \in P \quad (13)$$

Note that this sub-problem is NP-hard in the strong sense. Boysen et al. (2010) proposed an exact dynamic programming approach and a priority rule based heuristic start procedure to solve OBD-TRSP.

Conversely, the sequence μ of outbound trucks can be fixed starting from period T to earlier ones and be determined the optimal sequence of inbound trucks, respectively. However, this requires additional modifications to the mathematical model. Note that in the original model, objective function (1) was defined in such a way that it minimizes the index number of the service slot to which the last outbound truck in the sequence is assigned. As the outbound sequence is now not variable anymore, the objective function needs some adjustment. Makespan minimization can be readily expressed in terms of the inbound sequence by maximizing the first service slot to which any inbound truck is assigned. Let this slot in an optimal solution be denoted by t^*, then the first $t^* - 1$ slots, to which no inbound trucks are assigned, can be discarded and the minimum makespan is equal to $T - t* + 1$. It can be easily verified that both objectives lead to the same optimal inbound and outbound sequences.

Instead of defining IBD-TRSP as a maximization problem, a slightly different approach is taken which reveals an interesting relationship between IBD- and OBD-TRSP. Recall that in the original model, index t denotes the index number of a service slot in ascending order, so that a lower number indicates that the service slot is processed prior to a slot with a higher number, which is an intuitive representation of time. For IBD-TRSP, the point of reference is changed and a new time index $j = 1, 2, \cdots, T$ is introduced, where $j = 1$ refers to the service slot to which the last outbound truck is assigned and an increase in j denotes a movement backwards in time until service slot T, which now constitutes the earliest point in time to which any inbound or outbound truck could be assigned. Consequently, any original index t corresponds to $j = T - t + 1$. The IBD-TRSP can now be formulated as follows:

(IBD-TRSP): Minimize

$$M_{IBD} = max_{\alpha \in I; j=1, \ \dots, \ T} \{x_{\alpha j}.j\} \qquad (14)$$

subject to

$$\sum_{j=1}^{T} x_{\alpha j} = 1, \quad \forall \alpha \in I \qquad (15)$$

$$\sum\nolimits_{\alpha \in I} x_{\alpha j} \leq 1, \quad \forall j = 1, 2, \dots, T \qquad (16)$$

$$M_p - \left(\sum_{\tau=1}^{j} \sum\nolimits_{\alpha \in I} x_{\alpha\tau} \,.\, a_{\alpha p} \right) \geq M_p - B_{jp,} \quad \forall j = 1, 2, \dots, T; p \in P \qquad (17)$$

$x_{\alpha j} \in \{0,1\},\ \forall \alpha \in I; j = 1,2,\ ...\ ,T$ (18)

The objective function (14) minimizes the makespan in terms of the inbound sequence by minimizing the number of service slots between the last outbound and first inbound truck assigned. The constraints (15), (16) and (18) are simply modified according to the new time index j. The constraint (17) ensures that inbound trucks deliver product units in the required quantities, where $B_{jp} = \sum_{\tau=1}^{min\{|O|;j\}} b_{\mu T-\tau+1p}$, $\forall p \in P;\ j = 1,2,...,T$ denotes the total number of units of product p demanded by the last j outbound trucks in the fixed sequence μ and $M_p = \sum_{\alpha \in I} a_{\alpha p} = \sum_{\beta \in O} b_{\beta p}$ is the total number of parts delivered/demanded. Note that the constraint (17) can be rewritten as follows:

$$B_{jp} \geq \sum_{\tau=1}^{j} \sum_{\alpha \in I} x_{\alpha\tau} \cdot a_{\alpha p}, \qquad \forall j = 1,2,...,T;\ p \in P \qquad (19)$$

A comparison of IBD-TRSP and OBD-TRSP as formulated above, now reveals that their mathematical structures are identical. As a consequence, any algorithm for OBD-TRSP can be used to solve IBD-TRSP and vice versa. In fact, IBD-TRSP can be seen as a reverted OBD-TRSP, in the sense that the solution of an instance of IBD-TRSP with an algorithm designed for OBD-TRSP requires the following steps:

- Revert the given outbound sequence μ and set it as the modified inbound sequence π. Consider the set of inbound trucks I to be scheduled as the modified set of outbound vehicles O.
- Solve OBD-TRSP with the modified input data.
- The reverted optimal outbound sequence constitutes the optimal inbound sequence for the original IBD-TRSP instance.

Boysen et al. (2010) introduced an exact dynamic programming approach and a heuristic starting procedure to solve the identified sub-problems. The algorithmic descriptions are limited to OBD-TRSP, as they are directly transferable to IBD-TRSP as explained above.

Concluding Remarks

A model of makespan minimization problem in terms of absolute difference of operation times of inbound and outbound trucks is given. This model is slightly different than that of Boysen model, which considers the operation time of outbound truck. Supply chain logistics problem is the multi-level distribution problem, and this paper has considered only the logistics problem throughout the paper. The mutual coordination between production line and distribution line plays an important role in the overall supply chain management of the company. The cross-docking logistics (i.e., truck sequencing) problem is decomposed into two parts, namely inbound TRSP and outbound TRSP. The simultaneous study of multi-level just-in-time production and distribution systems will be the topic for further inquiry.

References

Beamon, B.M. (1998). Supply chain design and analysis: Models and methods. *International Journal of Production Economics, 55*: 281-294.

Boysen, N., Fliedner M. & Scholl A. (2010), Scheduling inbound and outbound trucks at cross docking terminals. *OR Spectrum, 32*: 135-161.

Buffa, F.P. (1986), Inbound logistics: Analysing inbound consolidation opportunities. *International Journal of Physical Distribution and Materials Management, 16*:3-32.

Christopher, M. (1998). Logistics and supply chain management. Strategies for reducing cost and improving service. Second ed., London.

Dhamala, T.N., Thapa G.B. & Yu H. (2012). An efficient frontier for sum deviation JIT sequencing problem in mixed-model systems via apportionment. *International Journal of Automation and Computing, 9*, 87–97.

Ghiani, G., Laporte G. & Musmanno R. (2004). *Introduction to logistics systems planning and control*. John Wiley and Sons Ltd.

Johnson, S.M. (1954). Optimal two - and three - stage production schedules with setup times included. *Naval Research Logistics, 1*, 61–68

Lee, H.L., Padmanabhan V. & Whang S. (1997). The bullwhip effect in supply chains. *Sloan Management Review, 38*, 93-102.

Li, Y., Lim A. & Rodrigues B. (2004). Crossdocking - JIT scheduling with time windows. *Journal of the Operations Research Society, 55*, 1342–1351.

McWilliams, D.L., Stanfield P.M. & Geiger C.D. (2005). The parcel hub scheduling problem: A simulation-based solution approach. *Computer Industrial Engineering, 49*: 393–412.

Oliver, R.K. & Webber, M.D. (1992). Supply chain management: Logistics catches up with strategy (reprint from Outlook 1982). In: Christopher, M. (Ed.), *Logistics-the Strategic Issues*, London, 63–75.

Otto, A. & Kotzab H. (1999). How supply chain management contributes to the management of supply chains–preliminary thoughts on an unpopular question. In: Larsson, E., Paulsson, U. (Eds.), *Building New Bridges in Logistics*. Lund University, 213–236.

Stadtler, H. (2002). Basics of supply chain management. In: Stadtler, H., Kilger, C. (Eds.)*, Supply Chain Management and Advanced Planning – Concepts, Models*. Software and Case Studies, Berlin, 7–28.

Stadtler, H. (2005). Supply chain management and advanced planning–basics, overview and challenges. *European Journal of Operational Research, 163*, 575–588.

Thapa, G.B. & Dhamala T.N. (2009). Just-in-time sequencing in mixed-model production systems relating with fair representation in apportionment theory. *The Nepali Mathematical Sciences Report, 29*, 29-68.

Thapa, G.B. & Silvestrov S. (2015). Supply chain logistics in multi-level just-in-time production sequencing problems. *Journal of Institute of Engineering, 11*(1), 91-100.

Thapa, G.B., Dhamala T.N. & Yu H. (2010). Mathematical models of cross-docking operations in supply chain logistics under multi-level just-in-time production environment. *The Nepali Mathematical Sciences Report 30*(1&2), 24-35.

Thapa, G.B., Dhamala T.N. & Pant S.R. (2014). Cross-docking operations for supply chain logistics in just-in-time production and distribution systems. *Journal of Institute of Engineering, 8*(1), 219-230.

Thapa, G.B. (2015). *Optimization of Just-in-Time Sequencing Problems and Supply Chain Logistics*, PhD Dissertation. Mälardalen University, Vasteras, Sweden.

Thapa, G.B. (2014). A comparative study on objective functions of product rate variation and discrete apportionment problems. *Journal of Institute of Science and Technology, 19*(1), 69-74.

Uday, M.A. & Viswanathan S. (2000). Effective cross docking for improving distribution efficiencies. *International Journal of Logistics: Research and Applications, 33*, 291-302.

Yu, W. & Egbelu P.J. (2008). Scheduling of inbound and outbound trucks in cross docking systems with temporary storage. *European Journal Operations Research, 184*, 377-396.