Enhancment of Inventory Management Approaches in “Vehicle Routing-Cross Docking” Problems

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ABSTRACT

A cross dock is the consolidation point in a distribution network, where multiple smaller shipments can be merged to full truck loads in order to realise economies in transportation. The focus of this study is to evaluate the possibility of considering inventory management structures in order to enhance the quality of solutions achieved by the classical VRP-Cross Dock (VRPCD) modeling. A mixed-integer programming is taken into account for locating cross docks and allocating Pickup and Delivery Nodes to them by considering each node’s time window in order to minimise the total transportation costs and inventory holding costs inside each cross dock which is the objective function of the modeling. “Direct Shipment” is used to attach Delivery and Pick-up nodes to cross dock facilities. Determining the necessity and amount of goods transshipment among cross docks is a key point in this modeling which causes a Semi-VMI behaviour by considering cross dock facilities as the coordinator base of the distribution network. The enhancement of the solutions by adding the ability of transshipment between cross docks is proved. Locating cross dock facilities (Strategic decision) while considering other technical issues (Operational decisions) is one of the major contributions of this study.

Keywords: Cross Docking, Inventory Management, Transportation, Mixed-Integer Programming, Facility Location Allocation

INTRODUCTION

Cross docking studies have mostly been concerned with the physical layout of a cross dock or technical characteristics of these facilities. Locationing, Door Assignment, Vehicle Routing, Truck Scheduling, Resource Scheduling and Packing-Unpacking decisions are the most popular decisions made in a distribution network containing cross dock facilities. Among those studies which addressed operational characteristics like those considering vehicle routing and cross docking simultaneously, few of them paid attention to the costs incurred by maintaining inventories inside cross docks. The reason may be that the classical definition of a cross dock emphasizes that these facilities are just consolidation points so that the maximum time that inventories can take in are fewer than 24 hours, but that’s not pragmatic in real world. Although this fact must not be a hindrance in consideration of inventory costs and a good reason for simplifying models by ignoring the cross docks inventory levels at each time, because beside the holding costs themselves are negative points for the whole distribution network even for such a short time, implementing inventory management for goods inside cross docks may lead to a total better performance of the whole supply chain, by taking better timing and allocating decisions (coordination). The focus of this study is on implementing some crucial improvements on one of the rare proposed models which considered inventory costs inside each cross dock. While the whole structure of the modeling is maintained, many different assumptions and constraints are devoted in order to achieve real world executable solutions, while sensitivity analysis will prove the applicability of the new modeling.

Due to the nature of this study we must first have a quick survey on the previous models in this area. A classification and review on the recent literatures could be helpful to which the third section is devoted. In the fourth section, we especially focus on the three mainly available models in this area which were from the first section, combining vehicle routing problems and problems considering the usage of cross dock facilities. In the next section, an extension for one of the above models which is the most suitable for considering inventory management in VRP-cross dock problems, proposed by Chen *et al*. (2006) is prepared. The next section is exclusively focused on three numerical examples and analysis of the results obtained by the extended model. Viability of such mechanism in real world is challenged based on the achieved results. In the seventh section, a brief conclusion and discussion will be an end for this study.

LITERATURE REVIEW

A cross docking facility or terminal is one of the distribution network nodes, which is particularly dedicated to transshipment of truck loads. The primary purpose of a cross dock is to enable a consolidation of differently sized shipments with the same destination to full truck loads, so that economies in transportation costs can be realized (Apte & Viswanathan, 2000). In some literature cross docking and short-term truck scheduling are considered as the same categories due to the nature of a cross dock facility to which timing and routing decisions are the most important decisions to be made (McWilliams *et al.*, 2005). Boysen *et al.* (2009) made a thorough and in-depth classification of cross docking problems by utilisation of a tuple $(\alpha_i, \beta_i, \gamma_i)$ which represents Door Environment, Operational Characteristics and Objectives, respectively which distinct each problem's origin (Boysen *et al.*, 2009). They implied that there are seven classes of decisions to be made in a cross docking problem which are: 1-Location of cross docking terminals, 2-Layout of the terminals, 3-Assignment of destinations to dock doors, 4-Vehicle Routing, 5-Truck Scheduling, 6-Resource Scheduling inside the terminals, and 7- (un-)Packing loads into (from) trucks. Location of cross docks (Tactical Decision) and vehicle routing (Operational Decisions) are focused in this paper. Investigation of a real world post office where delivered parcels are forwarded to outbound trucks by a system of interconnected conveyer belt is worth to mention (Apte & Viswanathan, 2000). Boysen (2010) discussed the complexity of distributing perishable goods while considering technical issues and routing decisions. The work of Lee *et al.* (2006) may be the first that takes both VRP and cross docking into consideration. The purpose of the modeling was to determine if vehicle k moves from node i to node j or not, while consideration of only one cross dock and zero inventory policy in all nodes beside pick-up and delivery structure with tour network arethe main characteristics of the formulation. Another effort in manipulating cross docking approach and vehicle routing simultaneously was made by Wen *et al.* (2009) which had inherited the structure from the first mentioned modeling with some justifications like elimination of "simultaneous arrivals" constraint and considering technical issues inside cross docks like load/unload order decisions. While in none of the modeling, inventory costs were taken into account, Chen *et al.* (2006) proposed a new formulation of vehicle routing and cross docking which consideration and minimisation of the inventory costs were the main idea of their mixed-integer modeling.

CLASSIFYING PREVIOUS VRPCDS

In this section we provide a classification for the three "vehicle routing- cross docking" modeling. Similarities and differences as preliminaries for introducing the new approach are discussed.

In literature we can find two different types of cross docking structures: 1-One-Touch Structure, and 2- Post Office Structure. In the first one, the simplifying level of the modeling is at the highest because one major assumption is that goods are unloaded, consolidated and loaded into trucks in a very short time and therefore there will be no inventories inside cross docks at any point of time. But in the second structure, which was firstly introduced by Donaldson *et al*. as a procedure to conquer the scheduling complexity of mail transshipment in U.S. post offices, the simplifying level is not that high, so the consolidation process like its counterpart in real world, takes time and therefore aggregated inventories and the scheduling (timing) are considered in the formulation. Another characteristic of the cross docking problems is the absence or presence of "information flow" in the distribution network. In the first class of models there are constraints such as $\sum_{i=1}^{n} P_i = \sum_{i=1}^{n} D_i$ which implies the equality of production and demand among all production and demand nodes, which is applicable in modeling dairy, flowers, and perishable goods distribution network. Consider that this leads to "zero inventory policy" in cross dock facilities.

Another important characteristic of a VRPCD is "Network structures". Direct shipments are used when production or demand in the corresponding nodes are equal or near to the maximum truck capacity while tour structures are used when this assumption is not valid and therefore routing decisions expand complexity of the problem."Product variety"and "Number of cross docks" are other noticeable characteristics of a VRPCD problem. Table 1 presents a classification of the three basic models based on the above-mentioned characteristics:

Table 1: Classification of Three Mainly VRPCDs Modeling

	Lee *et al.* (2006)	**Wen *et al.* (2009)**	**Chen *et al.* (2006)**
Inv. Inside CDs	Zero Inv. (One Touch)	Zero Inv. (One Touch)	Yes (Post Office)
Info. Flow	Yes	Yes	No
Network Structure	Tours	Tours	Direct Shipments
Product Variety	Single	Multiple	Multiple
Number of CDs	One	One	Two

Chen *et al*. formulation

After a brief review of Chen *et al*. modeling, the rest of this paper is dedicated to implement some improvements on the above formulation in order to enhance its real world applicability. Let’s define the different attributes:

Table 2a: Inputs

D	Set of m deliveries, indexed by i
P	Set of n pickups, indexed by j
C	Set of c cross docks, indexed by k
G	Set of d products, indexed by r
T	Set of times, indexed by t

Table 2b: Parameters

DP	Binary incidence matrix, 1 if product r is delivered by delivery i and 0 o.w
DA	Vector where $DA_i$is the amount delivered by delivery i
DD	Matrix where $DD_{i,\ k}$ is the distance from delivery I to cross dock k
DS	Vector where $DS_i$is starting time of delivery i
DE	Vector where $DE_i$is the ending time of delivery (define PP, P, PD, PS, PE for pickup node in the same way)
CAP	Vector where $CAP_k$is the capacity of cross dock k
COST	Vector where $COST_k$is the cost of handling a unit product for a unit time at cross dock k
T_{min}, T_{max}	Minimum and maximum times defining the time horizon

Table 2c: Decision Variables

$X_{i,\ k,\ t}$	Binary, 1 if delivery i is bound for cross dock k at time t, 0 o.w
$Y_{j,\ k,\ t}$	Binary, 1 if pickup j goes to cross dock k at time t, 0 o.w
$Z_{r,\ k,\ t}$	Integer, and is the amount of product r at cross dock k at time t

And the modeling is as below:

Minimize ($\mathrm{COST}_{\mathrm{Transportation}}$+$\mathrm{COST}_{\mathrm{inventory}}$)

where

$\mathrm{COST}_{\mathrm{Transportation}}$

$$=\sum_{i=1}^{m}\sum_{k=1}^{c}\sum_{t=T_{\min}}^{T_{\max}} x_{i,k,t}DD_{i,k}+\sum_{j=1}^{n}\sum_{k=1}^{c}\sum_{t=T_{\min}}^{T_{\max}} y_{j,k,t}PD_{j,k}$$

$$\mathrm{COST}_{\mathrm{inventory}}=\sum_{k=1}^{c}COST_k\sum_{r=1}^{d}\sum_{t=T_{\min}}^{T_{\max}} z_{r,k,t}$$

S.t:

$$2)\sum_{k}^{c}\sum_{t=PS_i}^{PE_i} x_{ikt}\leq 1(\forall i)$$

$$3)\sum_{k}^{c}\sum_{t=PS_j}^{PE_j} y_{jkt}=1(\forall j)$$

$$4)z_{rkt}\leq CAP_{k,r}(\forall r,k,t),\mathrm{T}_{\min}\leq t\leq T_{\max}$$

$$5)\,\mathrm{z}_{r,k,t-1}=0(\forall r,k,,t_{\min}),\mathrm{T}_{\min}\leq t\leq T_{\max}$$

$$6)z_{r,k,t}=z_{r,k,t-1}+\sum_{i=1}^{m}x_{i,k,t}DP_{i,r}DA_i-\sum_{j=1}^{n}y_{\mathrm{j},k,t}PP_{j,r}PA_j \text{ for}$$

all r, k and $\mathrm{T}_{\min}\leq t\leq T_{\max}$

$$7)z_{r,k,\mathrm{T}_{\min}-1}=0$$

The output is to determine when and to which cross dock each delivery node must transfer its goods (and as the same for pick up or demand nodes).

PROPOSED MODEL

By implementing major justifications on the introduced modeling and considering many different constrains and adding one important ability to the formulation, we can define contributions of our modeling as below:

- Considering production of different batches of different kinds of good in delivery nodes.
- Considering different batches of different kinds of goods demand in pick up nodes.

- Discrete locating of cross docks from a set of candidate locations and allocating delivery and pick up nodes to them.
- Consideration of different capacities and holding costs in each cross dock for each of the goods due to technical issues.
- Considering the ability of transferring goods between cross docks (which leads to a semi-VMI behaviour) by utilizing "revised inventory balance constraint".

Let's define the different attributes:

Table 3a: Parameters

$DP_{i,r}$	Binary incidence matrix, 1 if product r is produced at delivery node i, 0 ow (define $PP_{j,r}$ for the pickup node in the same way).
$DA_{i,r}$	Vector where $DA_{i,r}$ is the amount of product r delivered by delivery I (define $PA_{j,r}$ for the pickup node in the same way).
$DD_{i,k}$	Matrix, Distance between delivery node i and cross dock k. (define $PD_{j,k}$ for the pickup node in the same way).
$CAP_{k,r}$	Matrix, Capacity of cross dock k for product r.
$COST_{k,r}$	Matrix, Holding cost of Cross dock k for product r.
$D_{k,kk}$	Matrix, Distance between cross docks.
F_k	Fixed cost incurred if cross dock k is open.
hh_r	Unit cost incurred if one amount of product r is transferred between cross docks.

Table 3b: Variables

YY_k	1 if cross dock k is open, 0 o.w.
$RE_{r,k,kk,t}$	Integer, the amount of product r, transferred from cross dock "kk" to cross dock "k" at time "t".

The proposed formulation is as below:

Objective function:

Minimize ($COST_{Transportation}$+$COST_{inventory}$+$COST_{CD\ open}$)

Where:

$COST_{Transportation}$

$$= \sum_{i=1}^{m}\sum_{k=1}^{c}\sum_{t=T_{\min}}^{T_{\max}} x_{i,k,t} DD_{i,k} + \sum_{j=1}^{n}\sum_{k=1}^{c}\sum_{t=T_{\min}}^{T_{\max}} y_{j,k,t} PD_{j,k}$$

$COST_{inventory}$

$$= \begin{array}{l} \sum_{k=1}^{c} COST_k \sum_{r=1}^{d}\sum_{t=T_{\min}}^{T_{\max}} z_{r,k,t} + \\ \sum_{kk=1}^{c}\sum_{k=1}^{c}\sum_{r=1}^{d}\sum_{t=T_{\min}}^{T_{\max}} RE_{r,k,kk,t} * hh(r) * \mathrm{D}_{k,kk} \end{array}$$

$$\mathrm{COST}_{\mathrm{CD\ open}} = \sum_{k=1}^{c} \mathrm{F}_k * yy_k$$

Note: we assumed that cost incurred by transferring goods between two cross docks are proportional to destination between them ($D_{k,kk}$).

$s.\mathrm{t}:$

$$2)\sum_{k}^{c}\sum_{t=PS_i}^{PE_i} x_{ikt} \le 1(\forall i)$$

$$3)\sum_{k}^{c}\sum_{t=PS_j}^{PE_j} y_{jkt} = 1(\forall j)$$

$$4) z_{rkt} \le CAP_{k,r}(\forall r,k,t), \mathrm{T}_{\min} \le t \le T_{\max}$$

$$5)\, \mathrm{z}_{r,k,t-1} = 0(\forall r,k,,t_{\min}), \mathrm{T}_{\min} \le t \le T_{\max}$$

$$6) z_{r,k,t} = z_{r,k,t-1} + \sum_{k \ne kk}^{c} RE_{r,k,kk,t} - \sum_{kk \ne k}^{c} RE_{r,\mathrm{kk,k,t}} + \sum_{i}^{m} x_{ikt} DP_{ir} DA_{ir} - \sum_{j}^{n} y_{jkt} PP_{jr} PA_{jr}$$

$$7)\, yy_k \le 1(\forall k)$$

$$8)\sum_{i}^{m} x_{ikt} \le yy_k \;(\forall k,t)$$

$$9)\sum_{j}^{n} y_{jkt} \le yy_k(\forall k,t)$$

$$10)\sum_{r}^{d}\sum_{t=T_{\min}}^{T_{\max}} RE_{r,kk,k,t} \le yy_p * M(\forall k \ne kk)$$

$$11)\, \mathrm{yy}_p(k,kk) \le \mathrm{yy}_k(\forall k \ne kk)$$

$$12)\, yy_p(k,kk) \le yy_{kk}(\forall k \ne kk)$$

$$13)\, \mathrm{yy}_k + yy_{kk} - 1 \le yy_p(k,kk)(\forall k \ne kk)$$

Constraint (2) stipulates that it is not necessary to pick up goods from each delivery node while (3) shows the necessity of serving every pick up node in the distribution network. It means that the model is only obligated to serve all pick up nodes but not all deliveries and as long as we can satisfy demand of all pick up nodes with some of the deliveries, the constraints are satisfied too. Constraint (4) is revised by considering the $CAP_{r,k}$ which means the different capacity for holding different goods are taken into account, therefore we will have “r” times more of this kind of constraint compared to its original modeling counterpart constraint. Constraint (5) is an assumption which implies that at the beginning of time horizon of the problem we assume that all cross docks are empty and hold no inventories. One of the main ideas of this formulation is present in constraint (6) or “revised inventory balance constraint”, which stipulates that at any given time (meanwhile the defined time horizon), at each of the available cross docks and for all kinds of goods, the inventories must be balanced, while considering for every certain cross dock (k)the amount of a certain good (r) *browed from other (kk) cross docks* ($\sum_{kk\neq k}^{c} RE_{r,k,kk,t}$) and the amount of a certain good (r) *lend to other cross docks* ($\sum_{kk\neq k}^{c} RE_{r,kk,k,t}$)at any given point of time (t), must be equal to the total amount of that certain product, for that certain cross dock (k) and in that certain given time (t). Note that for means of simplification, we assume that transfer between cross docks occurs immediately. Constraints 8-13 are mentioned to manipulate the discrete cross dock locating from a set of candidate locations.

NUMERICAL EXPERIMENTS

This section is devoted to show the effectiveness of our modeling by introducing and executing an example containing 5 possible cross docks, 2 different kinds of goods and 3 delivery and pick up nodes with their certain time windows. These results were obtained using GAMS software version 11, executed by a laptop running on windows 7 operating system, having 2 GBs of RAM and Intel Core i5 CPU running at 2.4 GHz frequency. Tables 4-6 describe the parameters of the hypostatical example (1).

And consider $hh_1=180$ and $hh_{2}=190$ while $F_1=10$, $F_2=11$, $F_3=10$, $F_4=9$ and $F_5=10$.

Fig.1 illustrates the obtained results which can be described as below:

$x_{1,1,11} = x_{2,4,7} = x_{3,1,12} = x_{3,4,8} = 1$ Which means that for example delivery node 1, at time 11 connects to the cross dock 1 (and so on), and for pickups $y_{1,4,8} = y_{2,4,7} = y_{3,1,11} = y_{3,1,12} = 1$ with the same definition as for delivery nodes.

Table 4: Parameters Related to Delivery Nodes

	$DP_{i,1}$	$DP_{i,2}$	$DA_{i,1}$	$DA_{i,2}$	$DD_{i,1}$	$DD_{i,2}$	$DD_{i,3}$	$DD_{i,4}$	$DD_{i,5}$
i=1	1	1	190	110	14	18	14	15	20
i=2	1	1	140	70	14	12	12	9	6
i=3	0	1	0	120	13	12	6	18	19

Table 5: Parameters Related to Pick up Nodes

	$PP_{j,1}$	$PP_{j,2}$	$PA_{j,1}$	$PA_{j,2}$	$PD_{j,1}$	$PD_{j,2}$	$PD_{j,3}$	$PD_{j,4}$	$PD_{j,5}$
i=1	1	1	30	100	14	11	14	17	9
i=2	1	0	110	0	14	20	19	11	15
i=3	1	1	90	110	13	10	11	6	8

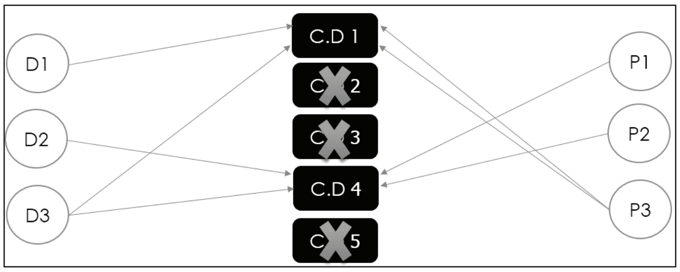
Table 6: Characteristics of Cross Docks

	$CAP_{k,1}$	$CAP_{k,2}$	$COST_{k,1}$	$COST_{k,2}$	$D_{k,1}$	$D_{k,2}$	$D_{k,3}$	$D_{k,4}$	$D_{k,5}$
k=1	110	80	100	110	0	11	40	16	20
k=2	90	80	125	115	11	0	19	18	21
k=3	150	90	115	120	40	19	0	50	19
k=4	100	110	105	95	16	18	50	0	60
k=5	80	90	95	110	20	21	19	60	0

Table 7: Time Windows of Each Delivery and Pick up Node

	DS_i	DE_i	PS_j	PE_j
i=1	1	12	-	-
i=2	3	11	-	-
i=3	5	6	-	-
j=1	-	-	3	7
j=2	-	-	5	9
j=3	-	-	4	10

Fig. 1: Obtained Results



The results only show the necessity of opening cross docks 1 and 4 ($yy_1 = yy_4 = 1$). The other classes of variables are $Z_{r,\ k,\ t}$ or the amount of aggregated inventories from every kind of products at each of the cross docks and any point of time which has been collected in Table 8.

Table 8: Inventory Level of Different Products at Different Cross Docks at Different Points of Times

	7	8	9	10	11	12
1.1	-	-	-	-	100	10
1.4	30	-	-	-	-	-
2.1	-	-	-	-	-	10
2.4	70	90	90	90	90	90

Figures 2 and 3 show the amount of aggregated inventories in available cross docks (1 and 4 are decided to be open) during the time.

Another kind of variables are $RE_{r,\ k,\ kk,\ t}$ (transshipments between cross docks) which at this run are all equal to 0 and therefore any transshipment did not occur between cross docks (because it was not "economical" or "necessary"). Consider that the optimal objective function value for example (1) is Z^*=64777.000.

Fig. 2: Aggregated Inventories at Cross Dock 1

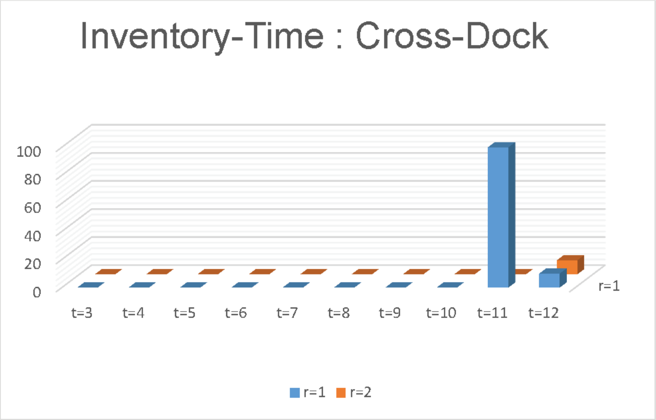
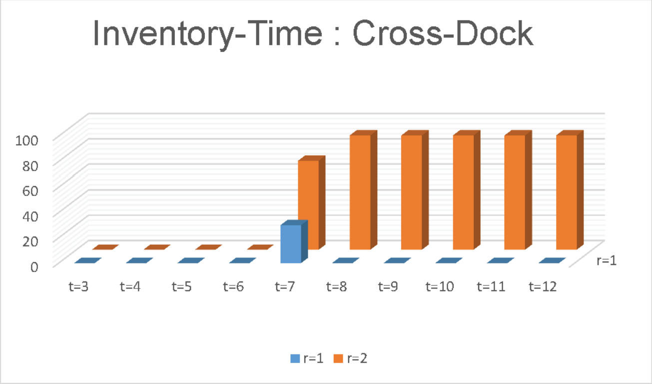


Fig. 3: Aggregated Inventories at Cross Dock 4



Sensitivity Analysis

In order to expose the applicability and effectiveness of the ability to transfer goods between cross docks, we need to another example. We do so by implementing some changes in parameters of the original example. Before that, let's define the situations in which, transshipment between cross docks becomes "economical" or "necessary":

- The cost of transferring goods between two cross docks is less than the holding cost of goods in the origin cross dock.
- There are capacity limitations for holding goods in the origin cross dock.
- Transshipment between cross docks by means of making "complete demand batches" and "making cross docks empty" which leads to a Semi-VMI behaviour of the modeling.

Now we assume that the holding cost in every cross dock hasa 300 percent increase (example 2). Therefore the justified $COST_{k,r}$ matrix becomes as shown in Table 9.

Table 9: Justified $COST_{k,r}$ matrix (example 2)

	1	2
1	300	330
2	375	345
3	345	360
4	315	285
5	285	330

The obtained results are described here:

$$x_{1,4,7} = x_{2,4,10} = x_{3,4,9} = x_{3,4,10} = x_{3,4,11} = 1$$

$$y_{1,4,8} = y_{1,4,9} = y_{1,4,10} = y_{1,4,11} = y_{2,4,7} = y_{3,4,10} = 1$$

$$RE_{r,k,kk,t} = RE_{2,1,4,7} = 10.00$$

We can see that due to a huge increase in holding costs in cross docks, model tries to empty cross docks at the end of planning horizon which leads to transferring 10 units of product 2, from cross dock kk=4 to cross dock k=1 at time 7. Another important thing is the semi-VMI behaviour which means that in order to make complete batches of demand and therefore enabling to make the cross dock empty at the end of the planning horizon, we must have more deliveries from delivery nodes (for example 3 times in a row, deliveries from node i=3 to cross dock k=4 at time 9, 10 and 11 are delivered) and consequently more pickups are scheduled than previous. Consider that the optimum value of the objective function in example (2) becomes 162132.000.

By eliminating the ability of transshipments between cross docks (in example (3)), we will show the effectiveness of adding such capability to the model. This is done by a tremendous increase in "transshipment unit cost between cross docks" or "hh_r" which has been shown in Table 10.

Table 10: Tremendous Increase in "Transshipment Unit Cost Between Cross Docks"

	hh_r
r=1	18000
r=2	19000

After running example (3), we see that there is not any transshipments between cross dock ($RE_{r,k,kk,t}$ = 0 for all r, k, kk, t) and the optimum value of the objective function increases to 194077.00. This fact proves the efficiency of adding "transshipment between cross docks" ability to the modeling. Fig.4 illustrates the increase of the total costs in example 3 compared to example 2.

Fig. 4: Increasing in Total Cost by Eliminating "Transshipment Between Cross Docks" Capability

CONCLUSION

Cross docking is considered as an efficient method to control the inventory flow, which is essential in a distribution network. The main difference between a cross docking facility and a distribution center is the duration of holding goods in these facilities. The definition of cross dock (holds goods for less than 24 hours) led to a gap in consideration of inventories costs in VRPCD literature, but the truth is by ignoring costs incurred by aggregation of inventories in cross docks, even for a very short time, the opportunity for making better scheduling and allocation decisions will be lost. To conquer the difficulties made by this level of simplification, our new model contributes five major approaches which are: 1- Discreet locationing of cross docks, 2- Allocating PickUp and Delivery demands to different cross docks, 3- The ability to transfer goods between cross docks, 4- Implementing a Semi-VMI structure (as a result), and 5- considering different capacity/costs for holding different goods at each of the cross docks. By utilisation of this new mixed-integer modeling, the numerical experiments showed about 12% decrease in the total cost by considering a much more intelligent inventory management approach inside cross docks. Also, making Strategic decisions such as cross dock locationing while considering Operational decisions such as allocating demands to cross docks and transferring goods between them are other contributions of our study. By implementing achieved solutions in practice, the management becomes aware if potential further dispatches to demand nodes (Semi- VMI Structure) are economic or not. This is done by taking optimized decisions about when and to (from) which cross dock collecting (dispatching) goods must take place.

Future studies on this area can be focused on expanding the proposed structure by consider routing decisions where "direct shipment" is no more the way of collecting and dispatching goods. Another trend can be defined by consideration of Soft Time Windows, where some penalties may compensate the costs associated with the resulted flexibility which makes the modeling much more realistic. Revising this structure for modeling distribution network of perishable goods is another probable application in this area.

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