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Scheduling Post-Distribution Cross-Dock under Demand Uncertainty

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Abstract

The system of distribution of goods and services, along with other economic developments around the world, is rapidly evolving. In the world of distribution of goods, the main focus is on making distribution operations more effective. Due to the fact that the cross-dock has the advantage of removing intermediaries and reducing the space required for the warehouse, it is worth considering. Among the methods of cross-docking, the post-distribution method is important in terms of uncertainty. Due to the importance of the issue of the post-distribution method in cross-dock, this paper addresses the uncertainty of demand in cross-docking. For this purpose, a linear programming model has been developed for post-distribution cross-dock, and then solved an example by the use of the meta-heuristic whale algorithm. After that, uncertainty enters the model and the robust counterpart of the model present based on the robust optimization approach with using interval and polyhedral collective inductive uncertainty set. The results shows the model could control the demand uncertainty in distance zero until 20 percent and the model does not let the changing of demand efforts considerably on the scheduling of the cross-docking.

Keywords: Scheduling, post-distribution cross-docking, demand uncertainty, robust optimization approach, collective inductive uncertainty set.

1. Introduction

As global competition increases, the efficiency and ability of these mechanisms is measured by consumers and retailers and determines future decisions. In 2010, Vogt [1] introduced a supply chain with a cross-dock as a supply chain that would include facilities of the cross-dock, and chain members share their facilities and capabilities for the entire supply chain, not just for a consumer. The

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success of the cross-dock depends so much on the proper flow of information and communication with other members of the supply chain. Meanwhile, how to manage operations within facilities of the cross-dock will also be effective on the success of the cross-dock. vary cross-docking exist in supply chains and play an important role as distribution centers in both delivering resources for production and delivering final product to consumers. The supply chain relationships, processes, and systems must work well for the success of the cross-dock. Cross-Dock is a logistical strategy for delivering products to the customer in less than 24 hours, and it is possible to bring products together and deliver them through trucks with full capacity. At a docking center, every day decisions are made about scheduling inputs and outputs, scheduling of unloading and loading and assigning them to doors and routing outgoing vehicles [2]. Cross-Dock is a logistics technique that removes storage and packaging operations from the warehouse and coordinates goods for unloading from inbound vehicles and loading on unbound vehicles (sorting and reorganizing) [3]. Cross-Dock has been recognized and accepted as a powerful tool for increasing the speed of the flow of goods and eliminating operations in the warehouse of goods and supply chains. Cross-Dock is a way to shorten the delivery time from the supplier to the customer. It is also an approach to reduce and even eliminate inventory levels of goods not stored in the warehouse, but are transmitted directly from the inbound truck to the outboard truck [4]. Cross-Dock is a new storage strategy and a transportation and distribution concept that, in addition to controlling logistics and distribution costs, simultaneously increases the level of service to customers [5]. Clearly, the cross-dock has significantly reduced the cost of organizing orders and holding inventory items. But because we are faced with uncertainty in the real world and uncertainties can lead to cost, hence the need to control the uncertainties is always there. Some of recent researches as important works on the cross-duck field of study are present. In 2016, Keshtzari et al. [6], examined the scheduling of vehicles and analyzed the mathematical model for larger problems with Taguchi's concept, and analyzed the problem for smaller issues, which method is better, and for larger issues only Comparison of methods. In 2016, Tutakale et al. [7] considered a dock that the outboard trucks visit the doors at a predefined time. In the previous models, trucks were loaded on the basis of the product. They assumed that products that are delivered late to the exit door are stored in temporary storage. In this way, if there is no proper cross-docking due to the delay in the processes, the products will wait to go until the vehicle that runs on the same track will receive them at the time of departure for delivery to the customer. In 2016, Cota et al. proposed a two-stage and universal problem and examined the limitations of the dock in reducing the lost time and developed an integer linear programming model based on the time function, and it was scheduled using cubic metaheuristic methods. In 2016, Amini and Tavakoli Moghaddam [2] perused the issue that trucks could fail, that the breakdown distribution estimated by Poisson distribution. They assumed that the delivery time of goods to the customer is constant. They solved the problem of truck scheduling with a two-objective mathematical model. Yin et al. In 2016 Yin et al. [8] carried out truck scheduling and routing for several temporary storage depots using geographic data and dock locations. They considered emergency warehouses and used statistical functions for uncertainties and implemented simulations for the entire dock. In 2016, Ladier and Alpan [3] looked at different models for a cross-dock for scheduling trucks at entry and exit doors. They expanded the old models. They used new techniques in scheduling with optimization processes to reduce waste resource and waste time. Fatthi et al. [9], in 2016, worked on lubricating and streamlining the cross-dock through the allocation of trucks to entry doors. They reviewed the sequence of trucks aimed at reducing total time. In 2016, Arkat et al. [10] proposed a mathematical model for scheduling entry and exit trucks with multiple-doors to reduce latency. They also tried to determine the time and place of unloading and loading. They thought that replacement of the products is possible, but the exit time would be constant and imperative. In 2017, Maknoon and Laporte [11], examined the issue of scheduling a cross-dock through a new meta-heuristic approach based on a large neighborhood search. In 2017, Wisittipanich and Hengmeechai [12] presented a mathematical mixed-integer programming model for the assignment of doors and sequences of trucks in multi-doors systems. The purpose of this model is to minimize overall operating time. The modified particle swarm optimization is designed to solve the truck scheduling problem in a multi-door system and compares the results with the results of particle swarm optimization approach. Experimental results show that their innovative method is able to find a high-quality solution with fast convergence. While most studies have been done on pre-distribution cross-dock, the present paper evaluates and examines the uncertainty of demand in a post-distribution cross-dock and simultaneously conducts scheduling with the aim of reducing time in distribution by post-distribution cross-dock method. Also it should be mentioned that consideration the effect of operations such as transmits and packaging of items and goods is very important in post-distribution cross-dock. In section2, the model of this paper is present and in section 3, the results of an example is show and the section 4, is the conclusion and suggestions of this research.

2. Research method

Based on the operations, facilities, conditions and strategies employed, generating various models for cross-dock is possible. In this paper a mixed-integer linear programming model is developed to show and examine the post-distribution cross-dock under certainty conditions, then by using robust optimization approach, the robust counterpart of the model is present.

2.1. Mathematical Model

Since the conditions of the post-distribution cross-dock are considered in the present model, there are constraints on the activity within the cross-dock in this model. Transmits, packing, unloading and loading are operations that affect the scheduling of the post-distribution cross-dock. Here, and in general, the cross-dock, the main issue is scheduling the arrival and departure of freight lorries and all post-distribution cross-dock activities. In this model, it was tried to minimize the time of completion of the work of the dock in addition to scheduling. What is important in the model is customer demand. The amount of inbound and outbound shipments and scheduling of all activities, as well as scheduling the arrival and departure of trucks, are all based on the amount of demand. The proposed model is a single-objective linear mixed-integer programming model. In the following, we introduce the assumptions, indices, parameters, and ultimately the objective function and the constraints.

2.1.1. Assumptions

The cross-dock system in this study will work as follows:
Inbound trucks drain their load in the entrance dock section and products are transported by the conveyor to the packaging and labeling sector and then transferred through the conveyor to the exit dock section and loaded in outbound trucks.

1. All inbound and outbound trucks are available at the beginning of the cross-dock, or so called zero time.

2. All items, products and shipments entered into the cross-dock should necessarily be left out of service until the completion of the dock activity and delivered to customers.

3. The total number of input items and output items must be equal.

4. The sequence of product unloading from the inbound truck can be determined.

5. The loading and unloading duration for all products are the same.

6. There is only one inbound dock and an outbound dock, and they are separate from each other.

7. The truck replacement duration has been considered in the queue for inbound and outbound.

8. The storage is prohibited and there will be no goods on the dock at the end of the dock activity.

9. Docking capacity is infinite.

10. It is not possible for all inbound and outbound trucks to go to the input dock and output dock at the same time.

11. Duration of loading and unloading for all item types is the same.

2.1.2. Notations

In this subsection indices, parameters and variables of the model are described. The notations are:

Table 1: Model notations

Notation	**Description**
$i, j = 1, 2, ..., I$	The index i and j are the counters of the number of incoming trucks
$o, k = 1, 2, ..., O$	The index o and k are the counters of the outboard trucks
$p = 1, 2, ..., P$	Index p is a counter of items and types of products
F	The time of completion of all the activities of the post-distribution cross-dock
D_p	Demand for item or product type p
NPI_{ip}	Parameter of the number of item type p in the i-th inbound truck
NPO_{op}	Parameter of the number of item type p in the o-th outbound truck
UUT_{ip}	Parameter of unit duration time for unloading inbound truck i-th
ULT_{op}	Parameter of unit duration time for loading outbound truck o-th
CCT	Parameter of duration of truck replacement in the docks
TTP	Parameter of the duration time for transfer of items from the input dock to the packing area
PT	Parameter of the duration time for packing and labeling operations
TTO	Parameter of the duration time for transfer of packages from packing area to the outlet dock
ITQ_{ij}	The binary variable is equal to 1 if in the inbound queue the i-th truck is ahead of the j-th truck
OTQ_{ok}	The binary variable is equal to 1 if in the outbound queue the o-th truck is ahead of the k-th truck
N_{iop}	The number of item type p unloaded from the i-th truck and loaded into the o-th truck
LAT_i	The arrival time of the i-th truck to the inbound dock, the continuous variable
ILT_i	The left time of the i-th truck from the inbound dock, the continuous variable
OAT_o	The arrival time of the o-th truck to the outbound dock, the continuous variable
OLT_o	The arrival time of the o-th truck to the outbound dock, the continuous variable

2.1.3. Certain model

$$\text{MiniZ} = \text{F} \tag{2.1}$$

s.t:

$$\sum_i N_{iop} \geq DP \qquad \forall p, o \tag{2.2}$$

$$\sum_o N_{iop} \leq NPI_{ip} \qquad \forall i, p \tag{2.3}$$

$$\sum_i N_{iop} \leq NPO_{op} \qquad \forall p, o \tag{2.4}$$

$$ILT_i \geq IAT_i + \sum_p NPI_{ip}UUT_{ip} \qquad \forall i \tag{2.5}$$

$$OLT_o \geq OAT_o + \sum_p NPO_{op}ULT_{op} \qquad \forall p, o \tag{2.6}$$

$$LAT_j \geq ILT_i + CCT - (1 - ITQ_{ij})M \qquad \forall i, j \; i \neq j \tag{2.7}$$

$$LAT_i \geq ILT_i + CCT - MITQ_{ij} \qquad \forall i, j \; i \neq j \tag{2.8}$$

$$ITQ_{ij} = 0 \qquad \forall i, j \; i \neq j \tag{2.9}$$

$$OAT_k \geq OLT_o + CCT - M(1 - OTQ_{ok}) \qquad \forall o, k \; o \neq k \tag{2.10}$$

$$OAT_o \geq OLT_k + CCT - MOTQ_{ok}) \qquad \forall o, k \; o \neq k \tag{2.11}$$

$$OTQ_{oo} = 0 \qquad \forall o \tag{2.12}$$

$$OLT_o \geq OAT_o + \sum_p \sum_i N_{iop}UUT_{ip} + \sum_p \sum_i N_{iop}TTP + \sum_p N_{iop}PT + \sum_p \sum_o N_{iop}TTO + \sum_p \sum_o N_{iop}ULT_{po} \qquad \forall i, o, p \tag{2.13}$$

$$F \geq OLT_o \qquad \forall o \tag{2.14}$$

$$N_{iop} \geq 0, int : ITQ_{ij} \in 0, 1; OTQ_{ok} \in 0, 1, \quad LAT_i \geq 0, ILT_i \geq 0, OAT_o \geq 0, OLT_o \geq 0 \tag{2.15}$$

Equation (2.1) states that the model seeks to minimize the completion time of all the cross-dock activities. Equations (2.2) to (2.4) show that the quantity of inputs and outputs are the same and equal to the amount of demand. Equation (2.5) indicates when the inbound truck leaves the inbound dock, and equation (2.6) indicates that the outbound truck leaves the outbound dock. The set of equations (2.7) to (2.9) represents the queues of the inbound trucks, and the set of equations (2.10) to (2.12) represents the queues of the outbound trucks. Equation (2.13) expresses the time of departure of the last outbound truck from the dock. Equation(2.14) states when the last outbound truck leaves the outbound dock, the daytime work of cross-dock is completed. Equation (2.15) is related to the model variables.

2.1.4. Robust counterpart of the model

After the certain model was implemented in MATLAB software and it was assured that the model was satisfactory, the uncertainty of demand can be introduced into the model. To write the robust counterpart of the proposed model we use the equation proven in research Li et al. [13]. The use of convex inductive uncertainty sets of interval, ellipsoidal, polyhedral and collective, leads to a conservative model. To reduce the degree of conservatism it could be used the collective uncertainty sets. Among the collective of the aforementioned sets, the collective of interval and polyhedral inductive uncertainty sets has the least conservative. The robust counterpart model of the present research model is expressed by using the collective of interval and polyhedral convex inductive uncertainty sets. As a result, the robust counterpart of the model is written as follows:

$$\text{MiniZ} = \text{F} \tag{2.16}$$

s.t:

$$\sum_i N_{iop} - \max(\Gamma, 1) * \widehat{D}_p * D_p \qquad \forall p, o \tag{2.17}$$

$$\sum_o N_{iop} \leq NPI_{ip} \qquad \forall i, p \tag{2.18}$$

$$\sum_i N_{iop} \leq NPO_{op} \qquad \forall p, o \tag{2.19}$$

$$ILT_i \geq IAT_i + \sum_p NPI_{ip} UUT_{ip} \qquad \forall i \tag{2.20}$$

$$OLT_o \geq OAT_o + \sum_p NPO_{op} ULT_{op} \qquad \forall p, o \tag{2.21}$$

$$LAT_j \geq ILT_i + CCT - (1 - ITQ_{ij})M \qquad \forall i, j \ i \neq j \tag{2.22}$$

$$LAT_i \geq ILT_i + CCT - MITQ_{ij} \qquad \forall i, j \ i \neq j \tag{2.23}$$

$$ITQ_{ij} = 0 \qquad \forall i, j \ i \neq j \tag{2.24}$$

$$OAT_k \geq OLT_o + CCT - M(1 - OTQ_{ok}) \qquad \forall o, k \ o \neq k \tag{2.25}$$

$$OAT_o \geq OLT_k + CCT - MOTQ_{ok}) \qquad \forall o, k \ o \neq k \tag{2.26}$$

$$OTQ_{oo} = 0 \qquad \forall o \tag{2.27}$$

$$OLT_o \geq OAT_o + \sum_p \sum_i N_{iop} UUT_{ip} + \sum_p \sum_i N_{iop} TTP +$$

$$\sum_p N_{iop} PT + \sum_p \sum_o N_{iop} TTO + \sum_p \sum_o N_{iop} ULT_{po} \qquad \forall i, o, p \tag{2.28}$$

$$F \geq OLT_o \qquad \forall o \tag{2.29}$$

$$N_{iop} \geq 0, int : ITQ_{ij} \in 0, 1; OTQ_{ok} \in 0, 1,$$

$$LAT_i \geq 0, ILT_i \geq 0, OAT_o \geq 0, OLT_o \geq 0 \tag{2.30}$$

Because the only uncertainty in demand is evaluated and examined in this study, the difference between the certain model and the robust counterpart model is in the first constraint, which is a special case of the robust optimization approach. Constraint (17) states that even in the presence of uncertainty in demand, the number of items and products entering by all the lorries to the cross-dock must necessarily meet the demand. In this model, the parameter Γ is the robust budget. This parameter balances between the robustness and the conservatism level of the model, according to the decision maker opinion and other requirements and makes the robust model a realistic one. $\widehat{D}$ is amount of perturbation in demand parameter. This perturbation is expressed as a percentage of variation in the parameter. Since the model presented in this article is an np-hard model, the whale meta-heuristic method is used to solve it.

3. Numerical Example

In this section, the proposed model is investigated by presenting a numerical example and solving it. In order to solve the model, the cross-dock considered has an entrance dock and an outlet dock. The number of inbound trucks is 100 trucks and the number of outbound trucks is 100 trucks in 24 hours. The variety of inputs items to this dock is 40 kinds of products, each with a different number. The truck capacity is 12,000 units. The time for switching trucks is the same and is 300 seconds and the time of carrying items from the inbound dock to the packing area is 60 seconds. The time of transmitting of items from the packaging zone to outbound dock is 60 seconds. The packing and labeling operation time is 120 seconds. The demand for each item is between 800,000 and 1,000,000 units.

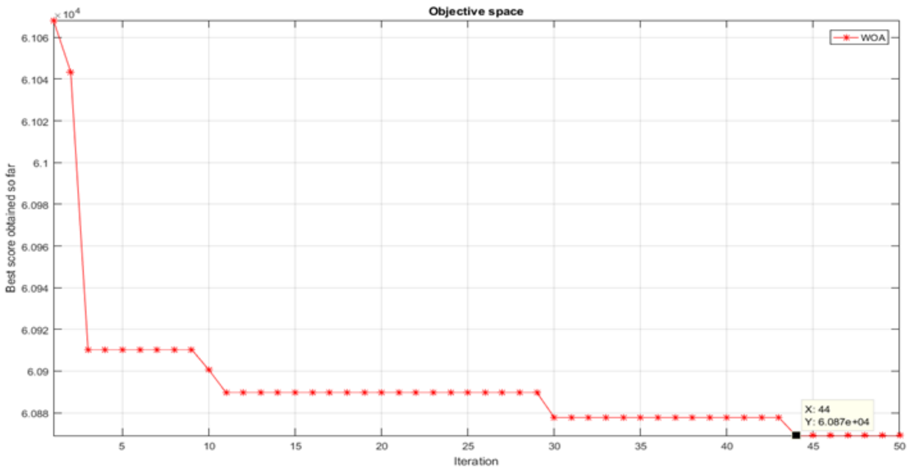

Figure 1: The certain model solving diagram

The purpose of this problem is to minimize the time of completion of the dock's activities. Since the solving method is a metaheuristic method, the solution of the certain model and robust counterpart model is repeated 10 times. It should be noted, however, that every time the model is repeated, the model iteration is 50 times. As shown in Fig.1, in the given example, in the case of certainty in the amount of demand, the completion time of the cross-dock's operations is 16 hours and 50 minutes, on average.

As Fig.2 under 5% uncertainty in demand, the total time of cross-ducking is 16 hours and 52 minutes.

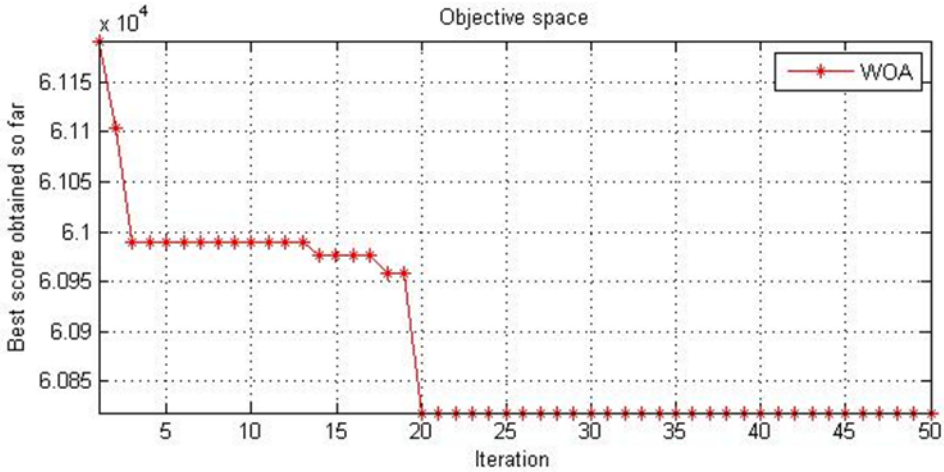

Figure 2: robust counterpart model solving diagram with 5% uncertainty in demand

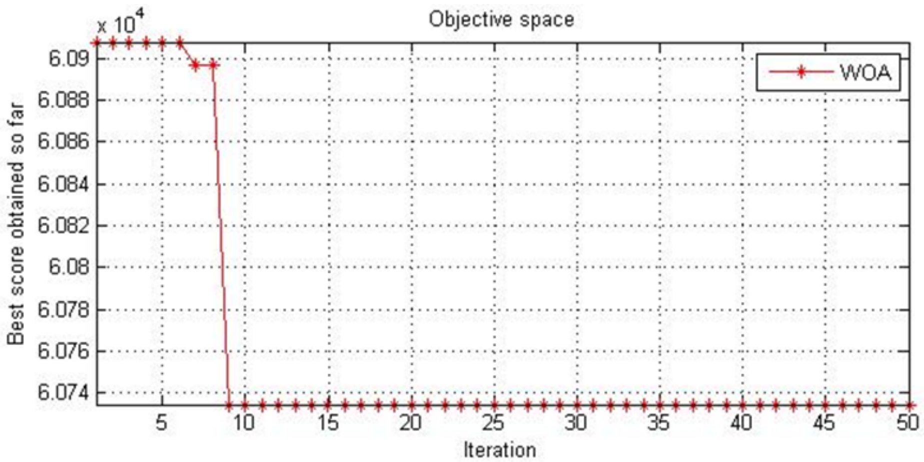

Figure 3: robust counterpart model solving diagram with 10% uncertainty in demand.

Under 10% uncertainty in demand, the total time of cross-ducking is 16 hours and 56 minutes.

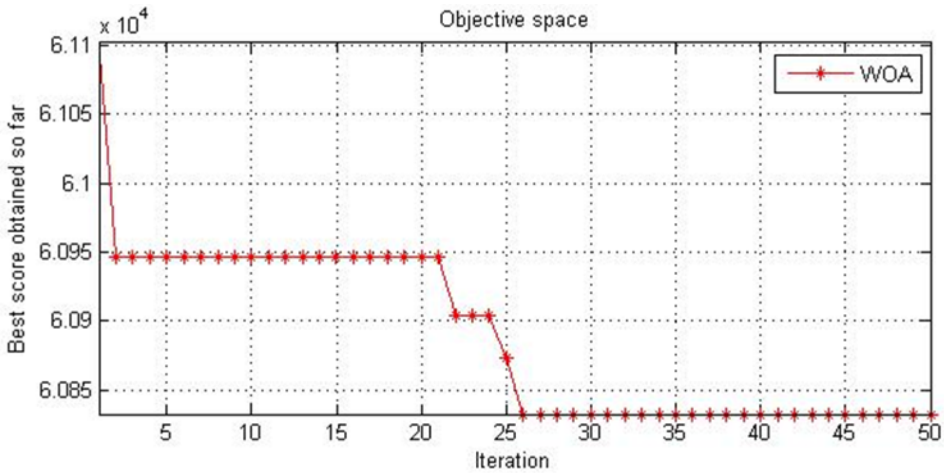

Figure 4: robust counterpart model solving diagram with 20% uncertainty in demand.

In the uncertainty of 20%, the optimal answer is convergent, the completion time of the dock operation from the start time is 17 hours and 3 minutes based on 10 times repetition of solving the robust counterpart model (Fig. 4).

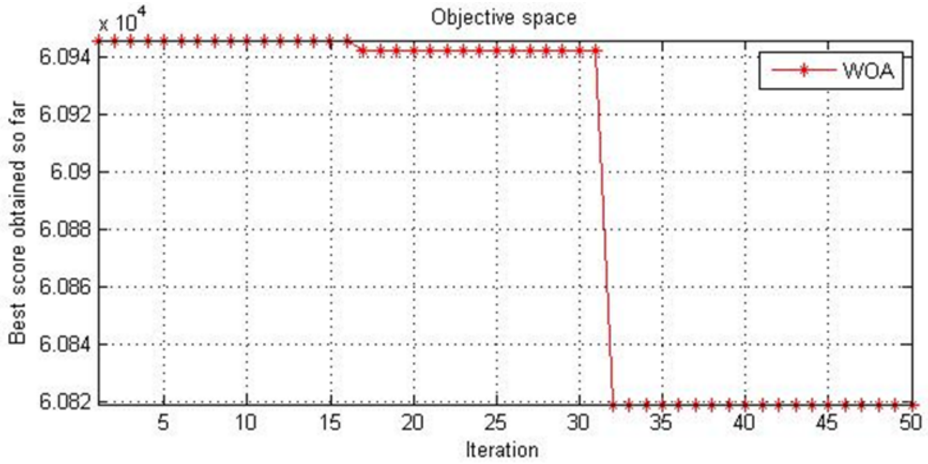

Figure 5: robust counterpart model solving diagram with 30% uncertainty in demand

Under 10% uncertainty in demand, the total time of cross-ducking is 17 hours and 26 minutes.

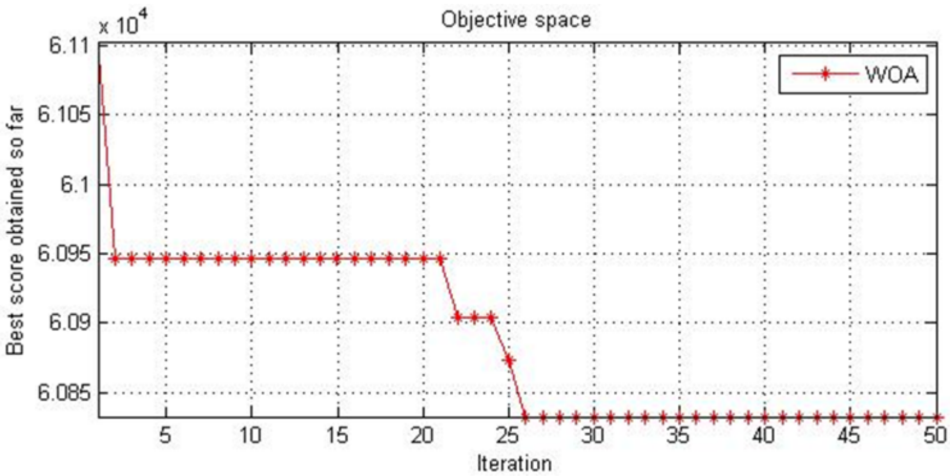

Figure 6: robust counterpart model solving diagram with 50% uncertainty in demand.

Under 10% uncertainty in demand, the total time of cross-ducking is 17 hours and 43 minutes. The uncertainty of 20% in demand is the only difference of 10 minutes during the operating time of the cross-dock. One might argue that the increase in the percentage of demand uncertainty would produce a greater difference, but the examination of this claim is inappropriate, because in the presence of uncertainty, it is expected that with 5% to 10% slight variations in input values, the output values undergo extremely changes. Therefore, our model could control the demand uncertainty in distance zero until 20 percent and the model does not let the changing of demand efforts considerably on the scheduling of the cross-docking. For more understanding, we consider the model by changing Gama as one factor of robust. We should know when Gama is going to 1 the model will be more conservative and in other way the model touches better results when Gama is going to zero. Then we investigate the results by different values of Gama.

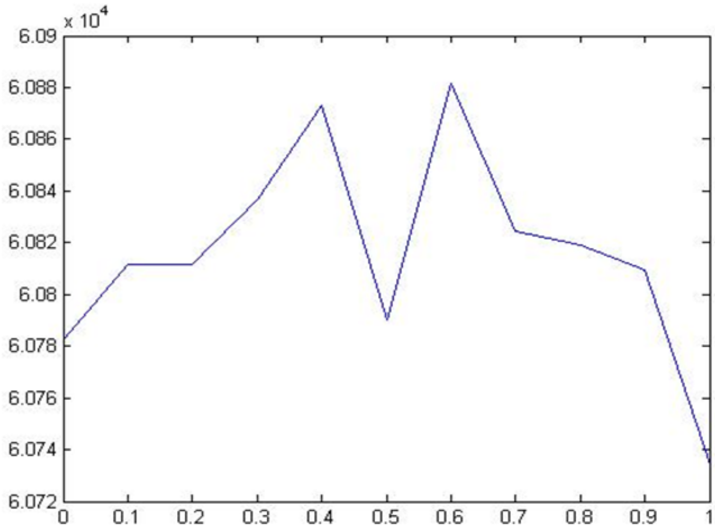

Figure 7: the best time of finishing the cross-ducking in 5% uncertainty demand with Gama [0, 1]

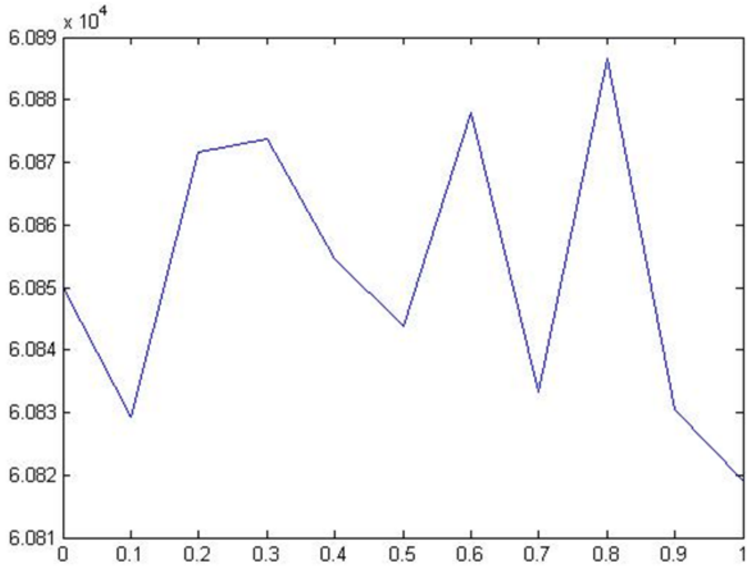

Figure 8: the best time of finishing the cross-ducking in 10% uncertainty demand with Gama [0, 1]

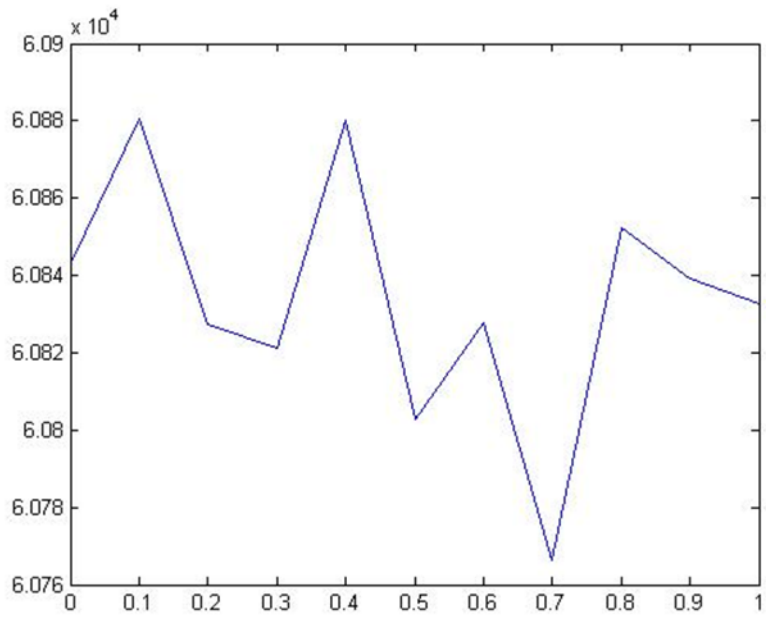

Figure 9: the best time of finishing the cross-ducking in 20% uncertainty demand with Gama [0, 1]

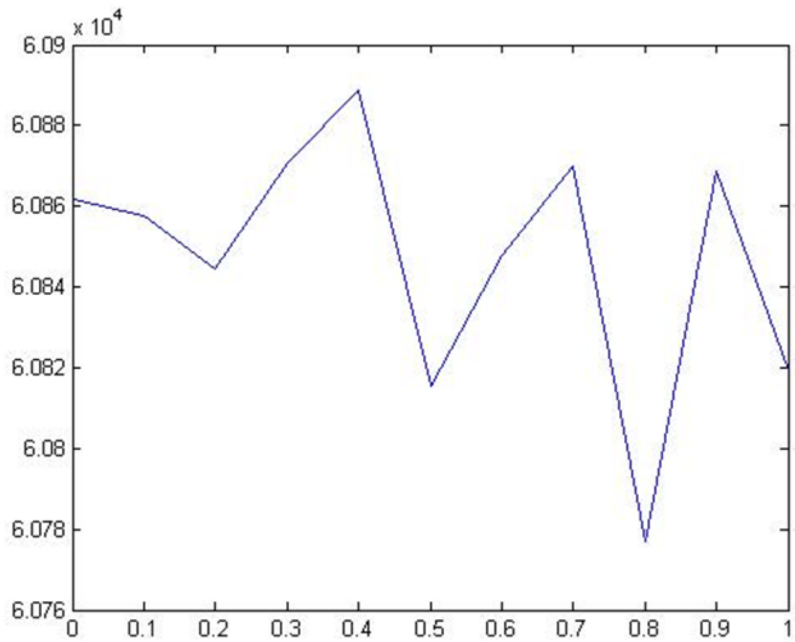

Figure 10: the best time of finishing the cross-ducking in 30% uncertainty demand with Gama [0, 1]

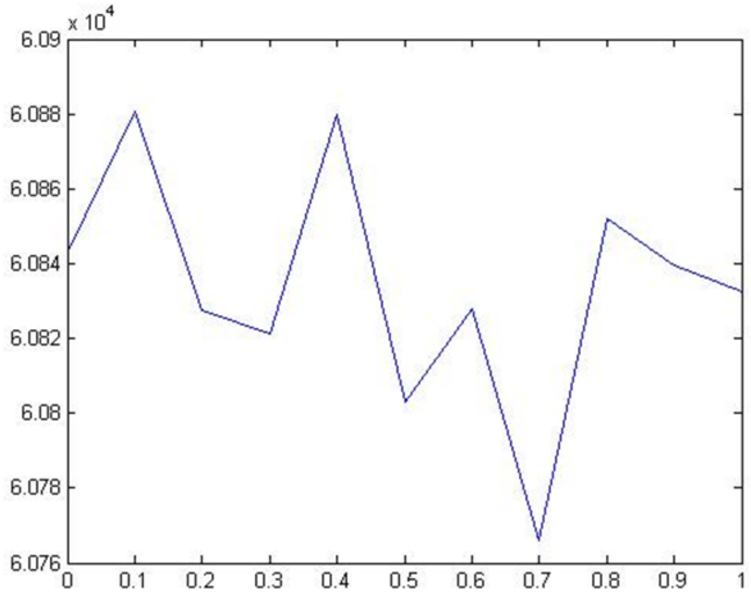

Figure 11: the best time of finishing the cross-ducking in 50% uncertainty demand with Gama [0, 1]

4. Conclusion

Due to the importance of the cross-dock and the scheduling issue therein, and generally in managerial issues, henceforth, it is necessary to identify the factors affecting the cross-dock, which, due to changes in conditions, these factors lead to risks and costs. The main objective of this study is to investigate the effect of demand uncertainty on the post-distribution cross-dock scheduling. In this research, we tried to show changes in uncertainty of demand in cross-dock by the post-distribution method with the goal of the minimum completion time of all planned activities. For this purpose at first a model developed for post-distribution cross-dock, then robust counterpart model present to peruse the effect of demand uncertainty on the scheduling of the dock. Finally, results shows that if uncertainty of demand is up to 20%, the model has the ability to control the resulting changes at the completion time in such a way that the entire completion time does not have a terrible change. To better explain the model, the model performance was tested in different variations of the sigma, which is one of the components of the robust method and indicates the level of conservatism of planning, and we presented the results. We can examine other components of the demand that have uncertainty about them in the future.

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