A Multiobjective Mathematical Model for Truck Scheduling Problem in Multidoor Cross-Docking System

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Received 20 April 2022; Revised 3 June 2022; Accepted 7 June 2022; Published 31 July 2022

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Cross-docking is the main operation of unloading products from incoming trucks, regrouping products in relation to their destination, and loading directly onto shipping trucks, reducing warehousing, picking, transportation costs, and delivery times. This is the intended logistics technology. In this paper, we present a new bi-objective mixed-integer mathematical model for truck scheduling problems in cross-docking systems. The goal of the proposed mixed-integer mathematical model is to minimize the total operation time (makespan) and cost of moving cargo within the terminal. The performance of the proposed model is compared with that of the available model to solve small instances. The results showed that in solving small size of problem, the proposed model in this study is more efficient and we found better solutions. An evolutionary algorithm called the nondominated sorting genetic algorithm (NSGA-II) has been proposed to solve larger instances due to computational complexity. To evaluate the proposed algorithm, a comparative analysis of benchmark instances was performed and the efficiency of the above algorithm was compared to the nondominated ranked algorithm (NRGA) based on the index designed in the literature. The statistical hypothesis testing (t-test) is used for determining the best algorithm based on the average runtime and average number of Pareto solutions. Using the Taguchi method, the proposed algorithms are tuned. Considering a temporary storage space and the multiple receiving and shipping docks is the main contribution of the paper. Finally, for evaluating algorithms, multicriteria decision-making (MCDM) technique and statistical method are used. The results show the suitable performance of presented model.

1. Introduction

Logistics costs have been the focus of all manufacturing and distribution companies for the past decade [1]. Companies are facing increasing pressure to reduce inventory and lead times and improve global efficiency. Logistics costs can be divided into three categories: inventory (including warehousing), transportation, and management costs, but transportation costs are the more influential part [2]. However, cross-docking is an approach that eliminates the two most costly processing operations of storage and picking [3]. Moreover, since approximately 30% of costs of each product are related to distribution process, numerous firms are attempting to develop their distribution strategies to achieve an effective flow management [4]. This paper is concerned with the introduction and modeling of a novel method in distribution system management that has attracted increasing attention in today’s world. Cross-docking is a relatively new technique in supply chain operations that consists of transferring cargo directly from inbound trucks to outbound trucks without intermediate storage [5]. The main objectives of implementing such a strategy are to reduce inventory levels and associated processing costs and integrate truck loading into the total truck loading, especially by reducing lead times for service levels and customer satisfaction. It is to improve the degree. Finding the best sequence of inbound and outbound of trucks reduces system operation and costs, and it is blindly obvious that this primary issue happening continuously in daily operation in cross-docking has a huge impact on the fast-moving process. Solving the problem of truck scheduling in cross-docking, which is one of the most
important extent issues in cross-docking system, is the issue of this research. In cross-docking, if the goods are to be stored, this will be possible for a very short time and up to 24 hours. This will reduce the time required to meet customer demand, inventory maintenance costs, and required space for storage. Generally, cross-docking is used when goods cannot be shipped directly. Operations generally performed in a cross-docking include [6] the following:

(i) Scheduling shipments to deliver goods from producers to cross-dock. It is required that goods deliver to cross-dock in accordance with specific time in scheduling, which is linked to shipping time.

(ii) Incoming goods are immediately sorted by demands of destinations. Outbound trucks can load and transport a combination of inbound goods and goods in a temporary storage location. A high degree of cooperation and coordination is needed to prevent any unwanted delays.

(iii) Orders (goods) move quickly to the shipping dock.

Compared with traditional docking, activities such as receiving inspection, storing, assembly, and ordering have been eliminated. Figure 1 shows the general operation of a cross-docking.

The following criteria can be considered as the cross-docking performance criteria [8]:

(i) The number of receiving and shipping docks required
(ii) Dock utilization
(iii) Average time of unloading and loading of trucks
(iv) Total time spent moving materials from receiving docks to shipping docks
(v) Total time required to perform cross-docking operations
(vi) Cost of moving and maintaining inventory

Depending on what type of strategy is being adopted concerning the facility and operating conditions, it is possible to define different models of cross-docking. Deciding on the quantity and quality of the following factors produces different combinations of models:

(i) The number of available docks in site
(ii) Pattern of entry and exit of trucks to docks (dock holding pattern)
(iii) The presence or absence of temporary storage

The cross-docking model scrutinized in this paper is one of the 32 models presented in [8] with separate receiving and shipping docks along with a temporary storage. The dock holding pattern of the trucks is also static and does not include the assumed model of cross-docking operation or distribution center such as scanning, weighing, labeling, and sorting. In addition, it is assumed that the temporary storage place is close to the receiving docks (Figure 2).

The practical applications of truck scheduling are vast and varied and are applicable in a variety of areas, such as software development, planning in major transportation organizations, airlines, post offices, chain stores, and many other areas. From a theoretical point of view, truck scheduling is a very attractive research field for researchers, especially planners. The well-known problem of truck scheduling in cross-dock is one of the problems of hybrid optimization with computational complexity of \(O(mn2^n)\) (m number of targets and n population size) [9]. In recent years, researchers’ interest and attempts in scheduling trucks in cross-docking have greatly increased, and many new modeling concepts and algorithms have been designed and implemented in this area, but according to expert researchers, there are still many shortcomings in this area, which are being from two aspects [10].

(i) Developing models closer to real issues
(ii) Improving problem-solving methods to enhance the quality of the solution and the problem-solving time

Although the issue of truck scheduling in cross-docking is very important from the practical point of view, perhaps the main reason for these shortcomings is the difficulty of problem-solving and improving the solution methods in enhancing the quality of the solution and improving the time of solving such problems. There are only few attempts to mathematically model the truck scheduling problem with respect to real constraints, and our model is more effective due to its size complexity. Therefore, efforts to address these shortcomings and simultaneously reduce the time and cost of operations by using new method make it necessary to conduct this research.

The goal of this paper was to present a model and study the problem of truck scheduling. When it comes to scheduling issues, total operation time is often referred to as makespan. In this study, makespan is defined as the total uptime for cross-docking operations. Total uptime is the time between the first product of the first scheduled inbound truck being unloaded at the receiving dock and the last product of the last scheduled outbound truck being loaded at the shipping dock. The purpose of this study was to find the best track docking sequence for both inbound and outbound tracks to minimize the total cross-docking uptime (equivalent to maximizing the throughput rate) of the cross-docking process. Product assignments from inbound trucks to outbound trucks are determined at the same time as the inbound and outbound truck docking sequences. The purpose of the problem is to reduce the total time to complete the operation and minimize the total costs of transshipment in the cross-docking. One of the most important advantages that has attracted a lot of attention to cross-docking is the characteristic of this method to reduce costs in the distribution system. In this study, minimizing the cost of transshipment goods is considered as one of the objectives of the model.

The rest of this paper is organized as follows. Section 2 summarizes some proposed papers applied in the case of truck scheduling in cross-docking systems. Section 3 briefly describes the mathematical model. This model serves as a
foundations for the heuristics and is also used to evaluate their performance to the best solution. Section 4 presents the heuristics used for the resolution of the problem. Section 5 addresses parameter setting and a method called the Taguchi plan in this case. Section 6 deals with the computational results and implementation of the algorithms, and finally, Section 7 is the conclusion and trends for future work.

2. Literature Review

The objective of this section is to analyze the existing literature in order to understand the problems and try to find the respective proposed approaches. Reference [10] reviewed and classified the literature of scheduling trucks in cross-docking. An important point is the strategic issues and operations that need to be paid attention and addressed in the cross-docking system life cycle, such as cross-docking location, design and layout of warehouse, transshipment routing, and warehouse resource planning, which, to further study on this area, one can refer to [3]. Since the issue of cross-stocking has attracted increasing attention in recent years, [11] undertook a wide-ranging study to identify the research gap between theoretical issues and real-world application challenges that reveal these differences. The most famous model for truck scheduling in cross-docking system presented by [7] investigated a cross-docking system in which a temporary storage buffer is located beside the shipping dock. The purpose of this study was finding the best scheduling sequence for both receiving and shipping trucks in receiving and shipping docks to minimize total operation time or increase the efficiency of cross-docking system. Some studies such as [12–14] try to develop the [7] mathematical model by considering different objectives such as earliness and tardiness or with different solving methods such as metaheuristic. There are few studies in the literature that have introduced the mathematical model for truck scheduling in multi-door cross-docking system. For instance, [15] presented a new mixed-integer programming model that is more efficient than the model presented by [7] and to demonstrate the efficiency of their model for large-scale problems used the hybrid heuristic algorithm for collective optimization of birds with a refrigeration simulation algorithm. Reference [16] describes a Lagrangian heuristic algorithm for a transit problem, where certain quantities of certain products must be transferred directly from a certain group of incoming trucks to a certain group of outgoing trucks. The goal is to plan activities and design transit plans, while minimizing the end time of the entire process. The main contribution of the paper is the Lagrangian decay diagram for the structured integer linear model of the problem. Reference [17] studied the problem of sequencing multiterminal trucks in a cross-connected hub with the aim of minimizing production time, and they came up with a parallel machine scenario. Instead of the traditional stream stores setup and proposes a polynomial parallel machine-based heuristic method that outperforms time-indexed math formulas and modern heuristics for small, medium, and large cases big (Shahmardan and Sajadieh [18], they proposed simulated annealing as a solution method. Reference [19] first proposed a mixed-integer linear programming model to optimally solve small instances. Next, two heuristics are proposed to solve the two problems in an integrated manner. These heuristics are as follows: vehicle routing cross-docking heuristic (VRCDH) and cross-docking vehicle routing heuristic (CDVRH) each focuses on one of the issues. On the other hand, among the recent studies, [20] can be mentioned that they assumed that freight trucks during their operations fail and the number of truck failures in a given period follows the Poisson distribution. They also set a deadline for each truck and used three heuristic algorithms to solve their two-objective model with the goal of reducing the number of delayed trucks and completing them and finally comparing the results of the three algorithms. Reference [21] introduced eight mixed-integer mathematical programming models for modeling the problem of door (dock) allocation to destinations in cross-docking environments and compared and introduced the best and most efficient models based on the standard examples available in the problem literature. Rashidi Komijan et al. [22] presented a school bus cross-dock and routing problem. The main contribution of their paper

| Receiving area | Temporary storage | Shipping area |
| Number of docks | Dock holding pattern | Number of docks | Dock holding pattern |
| Multiple | Stay | Yes | Multiple | Stay |

Figure 2: Studied cross-docking model [8].

Figure 1: General cross-docking operation [7].
was considering gender separation. Minimizing the transportation costs was the main objectives of their research. Khanchehzarrin et al. [23] presented a model for the time-dependent vehicle routing problem. Considering traffic condition is the main contribution of their paper. Reference [24] also presented two complex integer mathematical models for allocation door (dock) problem with the purpose of reducing displacement costs they used the generation columns algorithm to solve the models. The manner of waiting trucks to arrive the docks is one of the important issues studied by [25], and using the M/M/1 queueing theory model, remaining time for trucks was minimized; also, a two-objective model with the goals of reducing the cost of goods storage and reducing energy consumption in-warehouse transporters was presented and solved by two competing algorithms, Marguerite and gray wolf optimizer. Reference [26] presented a Tabu search approach to the truck scheduling problem with multiple docks. They considered minimizing the total travel time and the total tardiness as an objective [27]. Through a low-cost scheduling strategy, they addressed the issue of scheduling inbound and outbound trucks at the cross-dock facility when the arrival time of the vehicle was unknown. Two metaheuristics, MODE and NSGA-II, were used to solve the designed sampling problem and compare it to the random search-based genetic algorithms present in the literature. Khalili-Damghani et al. [28] presented a model for disaster hub location-allocation problem. The location problem was solved using GIS method, and the allocation problem was solved using the metaheuristic method. Shaﬁpour-Omrani et al. [29] presented the simulation-optimization model for liqueﬁed natural gas transportation. The main contributions of the presented model were considering hub location using the simulation method. The results of their paper show the suitable performance of their model. Reference [30] presented a mathematical model of mixed-integer programming for door assignments and track sequences in multidoor cross-docking systems. The goal of this model was to minimize total uptime or turnaround. Next, modiﬁed particle swarm optimization (so-called GLNPSO) with special encoding and decoding schemes was proposed to solve the track scheduling problem in multidoor cross-docking systems. Among the studies that are closely related to the model studied in this paper is [31] that introduced a multi-periodic cross-docking model considering the variable capacity of shipping and varied delivery time for shipping trucks by a complex integer programming and solved the model using an evolutionary computational approach based on a genetic algorithm whose results were compared to branch and case algorithm to evaluate the efficacy of the method. The difference between the above study and the model presented in this paper is to consider the temporary storage location in the mathematical model, as well as the multiple receiving and shipping docks of the trucks. Moreover, a multiobjective mathematical model presented in this paper includes reducing total operational time and costs of transporting inside the terminal. To solve the problem, nondominated storing genetic algorithm (NSGA-II) and nondominant ranked genetic algorithms (NRGAs) are applied and the results of two algorithms were compared and analyzed to identify a more effective algorithm. According to studies in the literature, considering a temporary storage space and the multiple receiving and shipping docks has a great effect on the efﬁciency of the model; therefore, it is necessary to address these shortcomings and bring the issue closer to the real situation. The literature review is shown in Table 1.

3. The Model

3.1. Indices

\[ i \] Receiving truck indices
\[ j \] Shipping truck counter
\[ k \] Merchandise counter
\[ m \] Receiving dock counter
\[ n \] Shipping dock counter
\[ R \] The number of receiving trucks
\[ S \] The number of shipping trucks
\[ M \] The number of receiving docks
\[ N \] The number of shipping docks

\[ P \] Types of goods

3.1.1. Parameters

\[ p_{ik}^t \] The number of \( k \)-type goods loaded into the truck \( i \) by default
\[ p_{jk}^t \] The number of \( k \)-type goods must be loaded into the truck \( j \)
\[ h_{jk} \] Time of loading (unloading) for the \( k \)-type good
\[ W_{mn} \] Time of transshipping of goods from the receiving dock \( m \) to the shipping dock \( n \) (for any quantity of goods of any kind)
\[ w_{n}^{TS} \] Time of transshipping the goods from temporary storage to shipping dock \( n \)
\[ C_k^D \] Cost of shipping the \( k \)-type good from receiving dock to shipping dock directly
\[ C_k^T \] Cost of shipping \( k \)-type good from the receiving dock to the temporary storage place
\[ C_k^{FS} \] The cost of moving \( k \)-type good from a temporary storage place to a shipping dock
\[ D \] Replacement time of trucks on docks
\[ Q \] Very large positive number

\[ x_{ijk}^D \] The number of \( k \)-type goods being transported directly from the receiving truck \( i \) to the shipping truck \( j \)
\[ x_{ik}^{TS} \] The number of \( k \)-type goods moved from the receiving truck \( i \) to the temporary storage location
\[ x_{ik}^{FS} \] The number of \( k \)-type goods moved from the temporary storage location to the shipping truck \( j \)
3.1.2 Variables

\( t_{ij} = \begin{cases} 1 & \text{If the good from the receiving truck } i \text{ is} \\ 0 & \text{transported to the shipping truck } j \end{cases} \)

\( p_{ij} = \begin{cases} 1 & \text{If the receiving truck } i \text{ overrides the receiving} \\ & \text{truck } j \text{ in the sequence of receiving trucks} \\ 0 & \text{otherwise} \end{cases} \)

\( q_{ij} = \begin{cases} 1 & \text{If the shipping truck } i \text{ overrides the shipping} \\ & \text{truck } j \text{ in the sequence of the shipping trucks} \\ 0 & \text{otherwise} \end{cases} \)

\( A_{im} = \begin{cases} 1 & \text{If the receiving truck } i \text{ is assigned to the} \\ & \text{receiving dock } m \end{cases} \)

\( B_{jn} = \begin{cases} 1 & \text{If the shipping truck } j \text{ is assigned to the} \\ & \text{shipping dock } n \end{cases} \)

\( Z_j = \begin{cases} 1 & \text{If the product is transported from the} \\ & \text{temporary storage to the shipping truck } J \end{cases} \)

\( d_{im} \) The time the receiving truck \( i \) enters the receiving dock \( m \)

\( l_{im} \) The time the receiving truck \( i \) leaves the receiving dock \( m \)

\( d_{jn} \) The time the shipping truck \( j \) enters the shipping dock \( n \)

3.2. Mathematical Model

\[
\text{Min } T, \quad (1)
\]

\[
\text{Min } C_T = \sum_{i=1}^{R} \sum_{j=1}^{S} \sum_{k=1}^{P} \left( C_{ik} D_{ijk} + C_{ik} T_{ijk} + C_{jk} F_{jk} x_{jk} \right). \quad (2)
\]

Subject to:

\[
T \geq l_{jn}, \quad \forall j = 1, 2, \ldots S, n = 1, 2, \ldots N, \quad (3)
\]

\[
M \sum_{m=1}^{M} A_{im} = 1, \quad \forall i = 1, 2, \ldots R, \quad (4)
\]

\[
R \sum_{i=1}^{R} A_{im} \geq 1, \quad \forall m = 1, 2, \ldots M, \quad (5)
\]

\[
N \sum_{j=1}^{N} A_{jn} = 1, \quad \forall j = 1, 2, \ldots S, \quad (6)
\]

\[
S \sum_{j=1}^{S} A_{jn} \geq 1, \quad \forall n = 1, 2, \ldots N, \quad (7)
\]

\[
\sum_{i=1}^{R} x_{ijk} + x_{jk} = p_{jk}, \quad \forall j = 1, 2, \ldots S, k = 1, 2, \ldots P, \quad (8)
\]

\[
\sum_{i=1}^{S} x_{ijk} + x_{jk} = p_{ik}, \quad \forall i = 1, 2, \ldots R, k = 1, 2, \ldots P, \quad (9)
\]

\[
R \sum_{i=1}^{R} T_{ik} = S \sum_{j=1}^{S} x_{jk}, \quad \forall k = 1, 2, \ldots P, \quad (10)
\]

\[
x_{ijk} \leq Q t_{ij}, \quad \forall i = 1, 2, \ldots R, j = 1, 2, \ldots S, k = 1, 2, \ldots P, \quad (11)
\]
\[ \begin{align*}
I_{im}^r & \geq d_{im}^r + A_{im}^r \sum_{k=1}^{p} p_{jk}^r \cdot h_k, \quad \forall i = 1, 2, \ldots, R, m = 1, 2, \ldots, M, \\
\end{align*} \]

(12)

\[ \begin{align*}
\bar{d}_{jm}^r & \geq I_{im}^r + D - Q(1 - p_0), \quad \forall i, j = 1, 2, \ldots, R, m = 1, 2, \ldots, M, i \neq j, \\
\end{align*} \]

(13)

\[ \begin{align*}
\bar{d}_{im}^r & \geq I_{jm}^r + D - Q p_{ij}, \quad \forall i, j = 1, 2, \ldots, R, m = 1, 2, \ldots, M, i \neq j, \\
\end{align*} \]

(14)

\[ \begin{align*}
\bar{d}_{im}^r & \geq d_{im}^r - Q p_{ij} - Q(1 - A_{im}^r) - Q(1 - A_{jm}^r), \\
\forall i, j = 1, 2, \ldots, R, m, n = 1, 2, \ldots, M, i \neq j, m \neq n, \\
\end{align*} \]

(15)

\[ \begin{align*}
P_{ui} = 0, \quad \forall i = 1, 2, \ldots, R, \\
\end{align*} \]

(16)

\[ \begin{align*}
I_{jn}^s & \geq \bar{d}_{jn}^s + A_{jn}^s \sum_{k=1}^{p} p_{jk}^s \cdot h_k, \quad \forall i = 1, 2, \ldots, R, m = 1, 2, \ldots, M, \\
\end{align*} \]

(17)

\[ \begin{align*}
\bar{d}_{jn}^s & \geq l_{jn}^s + D - Q(1 - q_{ij}), \quad \forall i, j = 1, 2, \ldots, S, n = 1, 2, \ldots, N, i \neq j, \\
\end{align*} \]

(18)

\[ \begin{align*}
\bar{d}_{jn}^s & \geq d_{jn}^s - Q q_{ij} - Q(1 - A_{jn}^s) - Q(1 - A_{jn}^s), \\
\forall i, j = 1, 2, \ldots, S, m, n = 1, 2, \ldots, N, i \neq j, m \neq n, \\
\end{align*} \]

(19)

\[ \begin{align*}
l_{jn}^s + Q(1 - A_{jn}^s) & \geq l_{jn}^s + W_{mn} + \sum_{k=1}^{p} x_{ij,k}^T \cdot h_k + \sum_{k=1}^{p} x_{ij,k}^S \cdot h_k \\
& \quad + \sum_{k=1}^{p} z_{ijn}^T \cdot h_k - Q(1 - t_{ij}) - Q(1 - A_{jm}^s) - Q(1 - A_{im}^s) - Q(1 - A_{jn}^s), \\
& \quad \forall i = 1, 2, \ldots, R, j = 1, 2, \ldots, S, m = 1, 2, \ldots, M, \\
& \quad n = 1, 2, \ldots, N, i \neq j, m \neq n, \\
\end{align*} \]

(20)

\[ \begin{align*}
l_{jn}^s + Q(1 - A_{jn}^s) & \geq l_{jn}^s + W_{mn} + \sum_{k=1}^{p} z_{ijn}^T \cdot h_k + \sum_{k=1}^{p} x_{ij,k}^S \cdot h_k \\
& \quad + \sum_{k=1}^{p} z_{ijn}^T \cdot h_k + 2 \cdot \sum_{k=1}^{p} p_{jk}^s \cdot h_k, \\
& \quad \forall i = 1, 2, \ldots, R, j = 1, 2, \ldots, S, m = 1, 2, \ldots, M, \\
& \quad n = 1, 2, \ldots, N, i \neq j, m \neq n, \\
\end{align*} \]

(21)

4. Solution Method

Different approaches have been applied to model and solve this problem. These approaches include mixed-integer
programming, branch and boundary techniques, search algorithms, full enumeration methods, and heuristic and metaheuristic algorithms. Full enumeration methods and mixed-integer programming have been used as the basic approaches to generate exact solutions, and metaheuristic algorithms have used these solutions to obtain the optimal responses. In the following, we will discuss in detail the different approaches to solve the problem of truck scheduling and studies in the field of cross-docking.

In this study, it is attempted to introduce an effective model that meets the needs of the day, by considering as far as possible the multiple objectives and considering constraints in real circumstance of truck scheduling problem. Twenty sets of test problems were randomly generated to test the performances of the mathematical model. Details on the test problems are presented in [8]. To validate the presented model, it was considered as the single-objective model with the aim of minimizing the total operation time, in a cross-docking warehouse with one receiving, and one shipping dock is coded and solved through GAMS software on a computer with 2 GB RAM and 2.53 GHz central processor and optimal solutions obtained by the proposed model have been compared with the model presented by [7] in Table 2. Data in Table 2 show that in small and medium size of problem our model is more efficient. In addition, to solve the two-objective problem, nondominated storing genetic algorithm (NSGA-II) and nondominated ranking genetic algorithm (NRGA) have been used. Optimization of multiobjective is different from single-objective issues because it contains several goals that must pay attention simultaneously to all goals in optimization. In this paper, we use two nondominated storing genetic algorithm and nondominated ranking genetic algorithm for large size of problem.

4.1. Controlled NSGA-II. Nondominated storing genetic algorithm is one of the most efficient and well-known multiobjective optimization algorithms presented by [32]. However, controlled NSGA-II presented by [33] is the same as NSGA-II, but here you use the concept of controlled elitism to create the next generation. The method of solving

| Problem set | Number of receiving trucks | Number of shipping trucks | Number of product types | Total number of products | Exact solution (makespan) | Optimal this study |
|-------------|----------------------------|----------------------------|-------------------------|--------------------------|--------------------------|-------------------|
| 1           | 4                          | 5                          | 4                       | 990                      | 1557                     | 1483              |
| 2           | 5                          | 4                          | 6                       | 1030                     | 1577                     | 1412              |
| 3           | 3                          | 3                          | 8                       | 890                      | 1372                     | 1300              |
| 4           | 5                          | 5                          | 8                       | 1000                     | 1749                     | 1503              |
| 5           | 5                          | 3                          | 8                       | 960                      | 1579                     | 1355              |
| 6           | 4                          | 4                          | 5                       | 1020                     | 1546                     | 1370              |
| 7           | 5                          | 4                          | 6                       | 980                      | 1535                     | 1330              |
| 8           | 3                          | 5                          | 7                       | 890                      | 1525                     | 1451              |
| 9           | 4                          | 4                          | 8                       | 900                      | 1473                     | 1334              |
| 10          | 3                          | 4                          | 9                       | 930                      | 1452                     | 1363              |
| 11          | 5                          | 4                          | 6                       | 1620                     | 2232                     | 1791              |
| 12          | 6                          | 4                          | 8                       | 1950                     | 2833                     | 2140              |
| 13          | 5                          | 6                          | 8                       | 1610                     | 2386                     | 1554              |
| 14          | 5                          | 5                          | 8                       | 1680                     | 2385                     | 1831              |
| 15          | 6                          | 5                          | 4                       | 2030                     | 2745                     | 2069              |
| 16          | 5                          | 6                          | 6                       | 1690                     | 2407                     | 2001              |
| 17          | 4                          | 4                          | 7                       | 1180                     | 1867                     | 1397              |
| 18          | 6                          | 6                          | 7                       | 1770                     | 2502                     | 1989              |
| 19          | 5                          | 5                          | 10                      | 1720                     | 2553                     | 2359              |
| 20          | 6                          | 6                          | 9                       | 2020                     | 2732                     | 2392              |
the above model is based on the nondominated storing genetic algorithm according to Figure 3.

4.2. Nondominated Ranking Genetic Algorithm (NRGA). A new population-based multiobjective evolutionary algorithm called genetic algorithm based on nondominated ranking nondominated has been successfully developed by [34] to optimize non-convex, nonlinear, and discrete functions. They studied multiobjective algorithms that worked on nondominated sorting. They noticed three problems in these algorithms.

(i) The computational complexity was $O(mn^2)$ ($M$: the number of targets and $N$: the population size)

(ii) Lack of efficient elitism

(iii) The need to specify parameters in the division process

Based on the problems in their previous approaches, they developed a new approach by combining the roulette wheeling algorithm based on ranking and the Pareto-based population ranking algorithm, which was named NRGA (nondominated ranking genetic algorithm). Their proposed algorithm solves the three problems in previous approaches. In this combination, a two-layer ranking based on the selection operator of roulette wheeling is offered, which randomly selects the new generation from the parent generation based on the selection of the best solutions (in terms of fit and extent). This algorithm is in most cases capable of achieving better scalability of the solutions at the Pareto boundary and the earlier convergence at the Pareto optimal boundary, compared with other multiobjective evolutionary algorithms. However, the difference between the NRGA and the controlled NSGA-II is in the strategy selection section and the population sorting and selection for the next generation.

4.3. Numerical Example. To illustrate the performance of the proposed strategy of the model, ten sets of problems were randomly generated, in medium and large size. Table 3 represents the size of the test problem sets. The number of product units unloaded from inbound trucks, or loaded onto outbound trucks, receiving and shipping trucks, and receiving and shipping docks are randomly generated from a uniform distribution over (5, 100). The data generated for medium and large size instances follow the restriction of a cross-docking system in which the inbound flow should be equal to the outbound flow. Each example is run 10 times by NSGA-II and NRGA in MATLAB software (R2009a) on a computer with 2 GB RAM and 2.53 GHz central processor. For one of the examples, an experimental design is employed to quickly converge and more accurately answer for the parameters of the two proposed algorithms. The Taguchi method is used here to set parameters.

5. Taguchi Method

There are several statistical methods for designing experiments to adjust the parameters of the algorithms. Taguchi improved a family of matrices of partial factorial experiments, so that after many experiments, he could design experiments in a way that the number of experiments for one problem reduced. In the Taguchi method, orthogonal arrays are used to study a large number of decision variables with a small number of experiments. Taguchi divides the factors into two main classes: controllable factors and sound factors. Sound factors are those that cannot be controlled directly. When removing sound factors is impossible, the Taguchi method seeks to minimize the impact of the sounds and determine the optimal level of controllable factors. The purpose of this study was to find the parameters of NSGA-II and NRGA as receiving variables to obtain the optimal response ($Y$). To set the problem parameter with 10 receiving trucks, 13 shipping trucks, 6 receiving docks, 5 shipping docks, and 5 different product types are reviewed. The Taguchi method has been used to adjust parameters of population size (Npop), probability of crossover (Pc), probability of mutation (Pm), and reproduction (Max Gen) in NSGA-II and NRGA. The Taguchi method here is applied for four factors at three levels, so that the factors are the same parameters of the two algorithms and each factor is at three levels.
levels. Table 4 shows the values of the factors at each level for NSGA-II and NRGA so that the numbers 1, 2, and 3 are the levels of each factor. The numbers in Table 4 are based on the trial and error method and the researchers’ suggestion.

Given the dual purpose of the model, the Taguchi parameters must be adjusted in the two-objective space. For this purpose, for the mentioned problem with 3 receiving trucks, 2 receiving docks, 4 shipping docks, 4 shipping trucks, and 6 different product types, at each level, the normalized weighted sum of the time algorithm performance criteria (CPU time), number of Pareto solutions (NOS), first objective function (completion time), second objective function (cost), and generational distance (GD) were calculated, so that the values obtained for each criterion from 10 times of the algorithm’s execution, based on nature of the positive or negative criteria, are normalized using a method according to the SAW principles. According to this method, the sum of the weighted values of the criteria is calculated at each level and the maximum value is used as the main parameter to calculate S/N ratios (here, it is assumed that the weight of the criteria is equal to 0.2). Now, considering the calculated values after 10 run times for each case and the S/N ratios for the different parameters of the problem for NSGA-II and NRGA, the average graphs of parameters for S/N rates at different levels are shown in

| Table 5: Best value of parameters for NSGA-II and NRGA. |
|-----------------|-----------------|
| NSGA-II         | NRGA            |
| Parameter       | Value           | Parameter       | Value           |
| Pc              | 0.85            | Pc              | 0.85            |
| Pm              | 0.2             | Pm              | 0.2             |
| Gen             | 100             | Gen             | 100             |
| NPop            | 50              | NPop            | 50              |

Figure 4: Values of different levels of parameters in S/N ratio for NSGA-II.

Figure 5: Values of different levels of parameters in the S/N ratio for NRGA.
Figures 4 and 5. Given equation (1), the lower the S/N ratio, the better the answers of algorithm. According to Figure 5, the optimal values of appropriate parameters for NSGA-II and NRGA are in accordance with Table 5.

\[
\frac{S}{N_s} = -10 \log \left( \frac{1}{n} \sum_{i=1}^{n} y_i^2 \right). \tag{25}
\]

6. Computational Result

In this section, five benchmarks are presented to evaluate multiobjective optimization algorithms:

6.1. Most Expansion. The below criterion measures the length of the spatial cube diameter applied by an ultimate measure of the objectives, for the set of nondominated solutions. Equation (26) illustrates the computational procedures of this index.

\[
D = \sqrt{\sum_{j=1}^{M} \max_{i} f_j^i - \min_{i} f_j^i}. \tag{26}
\]

6.2. Spacing. This following criterion calculates the relative distance of successive solutions using equations (27)–(29).

\[
S = \frac{1}{|n|} \sum_{i=1}^{n} \left( d_i - \bar{d} \right)^2, \tag{27}
\]

\[
d_i = \min_{m} \frac{\sum_{j=1}^{2} |f_j^m - f_j^i|}{|m|}, \tag{28}
\]

\[
\bar{d} = \frac{\sum_{i} d_i}{|n|}. \tag{29}
\]

The measured distance is equal to the lowest value of the sum of the absolute values of the difference in the values of the objective functions between the \(i\)th answer and the solutions in the final nondominated set. It is noteworthy that this distance criterion is different from the criterion of the lowest elucidation distance among the solutions.

6.3. Number of Pareto Solutions (NOSs). The NOS benchmark represents the number of optimal Pareto solutions that can be found in any algorithm. Figure 6 provides an example for calculating NOS.

6.4. Generational Distance (GD). This criterion finds the average distance of \(Q\) solutions from \(p^*\), instead of finding answers from the set of nondominated \(Q\) solutions belonging or not to the optimal Pareto solutions.

| Problem | \(D\)  | \(S\)  | NOS | GD  | \(T\) |
|---------|--------|--------|-----|-----|-----|
| 1       | 0.4283 | 4110.72| 3   | 18.132 | 37740 |
| 2       | 0.7345 | 2800.82| 7   | 19.44  | 173656 |
| 3       | 0.6532 | 2619.86| 24  | 18.61  | 5172159 |
| 4       | 0.9821 | 5445.06| 17  | 24.23  | 587126 |
| 5       | 0.8763 | 5701.82| 14  | 24.93  | 331846 |
| 6       | 0.4553 | 5367.43| 18  | 26.06  | 1759341 |
| 7       | 0.9234 | 4112.76| 18  | 19.01  | 1378814 |
| 8       | 0.8766 | 5723.18| 23  | 22.13  | 3333969 |
| 9       | 0.8661 | 4598.12| 35  | 19.87  | 19125443 |
| 10      | 0.9012 | 3892.74| 24  | 23.19  | 59399282 |

| Problem | \(D\)  | \(S\)  | NOS | GD  | \(T\) |
|---------|--------|--------|-----|-----|-----|
| 1       | 0.7802 | 4554.22| 12  | 17.66 | 174211 |
| 2       | 0.9871 | 3442.12| 3   | 18.92 | 38861 |
| 3       | 0.8993 | 3032.11| 32  | 16.23 | 5503859 |
| 4       | 0.9887 | 1790.21| 20  | 21.63 | 481018 |
| 5       | 0.7864 | 3309.28| 14  | 27.19 | 328979 |
| 6       | 0.7602 | 5466.09| 22  | 25.22 | 1765051 |
| 7       | 0.9103 | 5990.66| 23  | 24.93 | 1380413 |
| 8       | 0.8872 | 3354.88| 28  | 32.11 | 3344819 |
| 9       | 0.7898 | 4909.31| 35  | 19.87 | 19125443 |
| 10      | 0.9821 | 5891.01| 32  | 17.14 | 59388502 |
For $p = 2$, the $d_i$ parameter is equal to the Euclidean distance (in the target space) between the solutions of $i$ belonging to $q$ and the closest member of $p^*$. 

$$d_i = \min_{k=1}^{M} \left( \sum_{m=1}^{4} (f_{m}^{(i)} - f_{m}^{(k)})^2 \right)^{1/2}.$$ 

6.5. Algorithm Run Time (CPU Time). Another standard criterion for comparing multiobjective algorithms is the use of the algorithm’s runtime criterion, which is the lower this time, the better the algorithm’s performance.

After defining standard benchmarks for comparing Pareto-based multiobjective algorithms in Tables 6 and 7, these criteria are calculated for each of the experimental production problems, and then, based on the results, algorithms are studied statistically and using analytical methods. Since comparing the performance of algorithms on the basis of the values of one of the criteria does not provide a clear solution, therefore, the combination and synthetic methods are used to compare the algorithms and select the most efficient algorithm. One of these methods is the percentage of relative deviation. To measure algorithms, residual prediction deviation (RPD) is used whose computing method is based on

$$\text{RPD} = \frac{\text{Alg}_{\text{sol}} - \text{Best}_{\text{sol}}}{\text{Best}_{\text{sol}}} \times 100.$$ 

In this equation, $\text{Alg}_{\text{sol}}$ is the value obtained for each problem by the algorithm. $\text{Best}_{\text{sol}}$ is the best value among the solved sample issues. The lowest the average values of RPD, the better solutions obtained from the algorithm. The above criterion is calculated for two factors, the running time of the program ($T$) and the number of Pareto solutions ($P$). Moreover, it was implemented ten times for ten different problems that in Tables 8 and 9, the average values for desired criteria for NSGA-II and NRGA.

As Tables 8 and 9 illustrate, it is not easy to decide accurately which one of the two algorithms is more efficient than the other in averages of the number of solutions RPD ($\bar{T}$) and runtime RPD ($\bar{P}$). Therefore, two methods were used to evaluate the results of the two algorithms. Applying SAW method is one of the multiple-criteria decision-making methods or using statistical methods, which used one-way statistical hypothesis testing for runtime and number of solution averages.

6.6. Investigation of Results Using Multicriteria Decision-Making (MADM). To decide different problems, there are a large number of models. In general, these models are divided into two main categories, multicriteria decision-making models (MADMs) and multiobjective decision-making models (MODMs). By adopting MADM method, the decision-maker must select one or more of a limited set of alternatives so that each alternative was evaluated by at least 2 criteria. The simple additive weighting method (SAW) is the most popular method of MADM methods. SAW method is defined as follows: assume that $F$ is a decision matrix. First, a numerical scaling system, for example, normalization, is used to obtain the score for each alternative. A score in SAW method is the sum of the scores of all the criteria for each alternative in the decision matrix. In decision matrix $F$ equation (34) $A_r$ is alternative $r$, $B_i$ is $i$th criterion, and $X_{rij}$ is the value of alternative $r$ for $i$th criterion. In general, the value of an alternative in SAW method is calculated as follows:

$$V(A_r) = V_r = \sum_{j=1}^{n} w_j V_j(X_{rij}) r = 1.2 \ldots .L.$$

### Table 8: Values of RPD criteria for NSGA-II.

| Problem | $T$ | $P$ | Best $T$ | Best $P$ | $\bar{T}_{RPD}$ | $\bar{P}_{RPD}$ |
|---------|-----|-----|----------|----------|-----------------|-----------------|
| 1       | 0.4283 | 3  | 0.4185  | 3  | 2.35  | 0  |
| 2       | 0.4982 | 7  | 0.4282  | 9  | 16.35 | 17.77 |
| 3       | 0.7226 | 14 | 0.4416  | 30 | 63.62 | 52.33 |
| 4       | 0.4946 | 18 | 0.4209  | 31 | 17.52 | 42.90 |
| 5       | 0.9645 | 18 | 0.9470  | 27 | 1.85  | 32.60 |
| 6       | 0.9080 | 19 | 0.4482  | 30 | 102.58 | 37  |
| 7       | 0.5622 | 24 | 0.4500  | 37 | 24.94 | 35.67 |
| 8       | 0.9301 | 24 | 0.4988  | 36 | 86.43 | 33.05 |
| 9       | 1.1138 | 20 | 0.9744  | 38 | 14.31 | 42.84 |
| 10      | 1.4798 | 24 | 1.3758  | 41 | 7.55  | 40.48 |

### Table 9: Values of RPD criteria for NRGA.

| Problem | $T$ | $P$ | Best $T$ | Best $P$ | $\bar{T}_{RPD}$ | $\bar{P}_{RPD}$ |
|---------|-----|-----|----------|----------|-----------------|-----------------|
| 1       | 0.5235 | 4  | 0.4170  | 6  | 25.54 | 38.33 |
| 2       | 0.5211 | 13 | 0.4017  | 19 | 29.71 | 32.63 |
| 3       | 0.5279 | 15 | 0.4074  | 28 | 40.25 | 45.92 |
| 4       | 0.5355 | 21 | 0.4209  | 33 | 27.23 | 36.96 |
| 5       | 1.0174 | 24 | 0.9306  | 38 | 9.32  | 37.90 |
| 6       | 0.9381 | 23 | 0.9104  | 39 | 30.3  | 41.53 |
| 7       | 0.8109 | 28 | 0.4398  | 40 | 84.38 | 29  |
| 8       | 0.7452 | 32 | 0.4447  | 39 | 65.57 | 17.94 |
| 9       | 1.0331 | 36 | 0.9926  | 40 | 4.07  | 11   |
| 10      | 1.5206 | 32 | 1.4012  | 44 | 8.51  | 27.27 |
In the above equation, $L$ is the number of alternatives, $n$ is the number of criteria, $V_j(x_i,j)$ is the value of $i$th criterion under the $j$th alternative, and $w_j$ is the weight of $j$th alternative.

In this study, NSGA-II and NRGA, alternatives (choices), makespan, and total cost are also criteria. Here, the criteria were weighted after normalization (the criteria weight is considered to be 0.5) and the best execution of each problem is selected by SAW method. Tables 10 and 11 show the results for NSGA-II and NRGA.

The results of Table 12 show that, in general, considering two criteria makespan and total cost, NSGA-II is more efficient than NRGA from SAW perspective.

### Table 10: Superior performance of each problem based on SAW method for NSGA-II.

| Problems | CPU time (second) | Total cost | Makespan (second) | Pareto solution |
|----------|------------------|------------|-------------------|-----------------|
| 1        | 0.440915         | 741        | 36055             | 3               |
| 2        | 0.431867         | 26531      | 175532            | 6               |
| 3        | 0.497491         | 41031      | 324173            | 29              |
| 4        | 0.431391         | 48770      | 573148            | 21              |
| 5        | 0.946947         | 87931      | 1406232           | 13              |
| 6        | 0.463434         | 103839     | 1756427           | 29              |
| 7        | 0.463434         | 185443     | 3287332           | 29              |
| 8        | 0.498891         | 140617     | 2181641           | 19              |
| 9        | 0.979835         | 1433406    | 19106634          | 13              |
| 10       | 1.50751          | 6382844    | 59334353          | 29              |
| Average  | 0.6661608        | 845115.3   | 8818060.9         | 19.1            |

### Table 11: Superior performance of each problem based on SAW method for NRGA.

| Problems | CPU time (second) | Total cost | Makespan (second) | Pareto solution |
|----------|------------------|------------|-------------------|-----------------|
| 1        | 0.417008         | 741        | 36015             | 4               |
| 2        | 0.423161         | 26530      | 173208            | 15              |
| 3        | 0.427635         | 41032      | 323804            | 27              |
| 4        | 0.454585         | 131655     | 63312             | 33              |
| 5        | 0.979052         | 79483      | 1370871           | 10              |
| 6        | 0.914421         | 172774     | 1784343           | 9               |
| 7        | 0.952752         | 185856     | 3334967           | 33              |
| 8        | 0.523281         | 278420     | 5508685           | 35              |
| 9        | 0.992697         | 1592228    | 19135640          | 40              |
| 10       | 1.546402         | 7600860    | 59414621          | 44              |
| Average  | 0.7629194        | 10110957.9| 9114546.6         | 25              |

### Table 12: Comparison of results for all issues.

|                | Average makespan (second) | Average total cost |
|----------------|---------------------------|--------------------|
| NSGA-II        | 881806.09                 | 84511.3            |
| NRGA           | 9114546.6                 | 1010957.9          |

In the above equation, $L$ is the number of alternatives, $n$ is the number of criteria, $V_j(x_i,j)$ is the value of $i$th criterion under the $j$th alternative, and $w_j$ is the weight of $j$th alternative.

$$ F = \begin{bmatrix} A_1 & \cdots & A_n \end{bmatrix} \begin{bmatrix} x_{i1} & \cdots & x_{in} \end{bmatrix}$$

In this study, NSGA-II and NRGA, alternatives (choices), makespan, and total cost are also criteria. Here, the criteria were weighted after normalization (the criteria weight is considered to be 0.5) and the best execution of each problem is selected by SAW method. Tables 10 and 11 show the results for NSGA-II and NRGA.

The results of Table 12 show that, in general, considering two criteria makespan and total cost, NSGA-II is more efficient than NRGA from SAW perspective.

6.7. Result Analysis Using Statistical Method. To compare the results of NSGA-II and NRGA retained in this method, a statistical method was applied. Here, two one-way assumption tests for values of $RPD(P)$ and $RPD(T)$ for NRGA and NSGA-II were considered. In this example, the confidence coefficient is equal to 0.95. It means $(1 - \alpha = 0.95)$.

Equations (35)–(38) show one-way statistical tests for $RPD(P)$ and $RPD(T)$ and values of $t$-distribution for $RPD(P)$ and $RPD(T)$, respectively, so that $T$ is defined as the runtime average and $P$ is equal to the average of the number of solutions. This test is performed assuming that variances are known.

$$ H_0: \mu_{T_{\text{NRGA}}} \geq \mu_{T_{\text{NSGA}}}, $$

$$ H_1: \mu_{T_{\text{NRGA}}} < \mu_{T_{\text{NSGA}}}, $$

$$ H_0: \mu_{P_{\text{NRGA}}} \geq \mu_{P_{\text{NSGA}}}, $$

$$ H_1: \mu_{P_{\text{NRGA}}} < \mu_{P_{\text{NSGA}}}, $$

$$ t_{\text{Distribution}} = \frac{T_{\text{NRGA}} - T_{\text{NSGA}}}{S_T \sqrt{1/n_{\text{NRGA}} + 1/n_{\text{NSGA}}}} $$

$$ t_{\text{Distribution}} = \frac{P_{\text{NRGA}} - P_{\text{NSGA}}}{S_T \sqrt{1/n_{\text{NRGA}} + 1/n_{\text{NSGA}}}} $$
In the above equation, $S_{p}^2$ is defined as follows in which $S_{NRGA}^2$ and $S_{NSGA}^2$ are equal to sample variance for NSGA-II and NRGA. If $t_{distribution} > t_{1-\alpha}$, thus, $H_0$ is rejected and $H_1$ is accepted; otherwise, $H_1$ is rejected and $H_0$ is accepted.

$$S_{p}^2 = \frac{(n_{NRGA} - 1)S_{NRGA}^2 + (n_{NSGA} - 1)S_{NSGA}^2}{n_{NRGA} + n_{NSGA} - 2}$$

(39)

The results of RPD($T$) values for ten examples made here, after solving by presented algorithms, are given in Tables 11 and 12. The calculation is as follows:

$$t_{Distribution} = \frac{29.96 - 33.74}{1050.47\sqrt{1/10 + 1/10}} = -0.008,$$

$$t_{0.95,18} = 1.73.$$ 

According to the above calculations, $t_{distribution} > t_{0.95,18}$ is not established; thus, $H_1$ assumption is rejected and $H_0$ is accepted. Therefore, given the lower the average number of solutions, the better, then, NSGA-II is better than NRGA regarding RPD($T$) criterion. The study of results with statistical method showed that NSGA-II is better than NRGA in terms of two criteria RPD($P$) and RPD($T$). The results of RPD($T$) values for ten examples made here, after solving by presented algorithms, are given in Tables 8 and 9. The calculation is as follows:

$$t_{Distribution} = \frac{31.84 - 33.86}{172.78\sqrt{1/10 + 1/10}} = -0.026,$$

$$t_{0.95,18} = 1.73.$$ 

According to the above calculations, $t_{distribution} > t_{0.95,18}$ is not established; thus, $H_1$ assumption is rejected and $H_0$ is accepted. Therefore, given the lower the average runtime, the better, then, NSGA-II is better than NRGA regarding RPD($T$) criterion. The study of results with statistical method showed that NSGA-II is better than NRGA in terms of two criteria RPD($P$) and RPD($T$).

6.8. Managerial Insights and Practical Implications. The results of this study can be useful for organizations such as municipalities, transportation organizations, and organizations that are somehow related to traffic. One of the advantages of the presented methods is that NSGA-II and NRGA use only the values of the objective function to perform the optimization process and do not require additional information such as the function derivative. Also, the disadvantages of the proposed methods are that the final solution in NSGA-II and NRGA depends on the coder’s skill in defining chromosomes and the initial value of its parameters.

7. Conclusion and Future Research

In this study, the problem of scheduling trucks in a cross-docking system, to minimize time of the whole process and cost of handling inside the terminal, has been investigated. To be more realistic, the cross-docking problem was considered with multiple receiving and shipping docks. Also, we assumed that there is a temporary storage facility near the shipping docks with limited capacity. The developed model was solved by GAMS software, and the obtained solutions were compared with the model presented in [7]. The results showed that in solving small size of problem, the proposed model in this study is more efficient and we found better solutions for objective function (makespan).

Due to the complexity of multiobjective mathematical model, two different metaheuristic algorithms (NSGA-II and NRGA) were applied to solve the medium and large size of problem. Due to getting better result, the proposed algorithms were tuned by applying the Taguchi method. To decide which algorithms are more effective, two methods were used to compare the results of the two algorithms: the two metaheuristic algorithms (NSGA-II and NRGA) were compared based on 4 criteria (CPU time, total cost, makespan, and number of Pareto solution) by means of SAW method, which is one of the multicriteria decision-making methods. The statistical hypothesis testing ($t$-test) is used for determining the best algorithm based on the average runtime and average number of Pareto solutions. Finally, both methods showed that NSGA-II metaheuristic algorithm was more effective than NRGA metaheuristic algorithm and provided better solutions. As there was no official database for some parts of cost elements, the driver’s estimations were asked to help. The questions about the shipping costs for each route have been categorized, and the estimated costs have been entered into the mathematical model.

The future research suggestions of this paper can be divided into two parts:

(i) Development of methods such as Tabu search algorithm, ant colony optimization, and particle swarm optimization for the problem and comparison with the proposed methods

(ii) Exploring the feasibility of utilizing intelligent combination systems and hybrid heuristic methods for model development

(iii) Using other methods, for tuning problem parameters

(iv) Changes in the structure of the problem

In the model presented in this paper, the dock holding pattern was considered static, so one of the topics for future research could be different dock holding patterns. In this research, it is assumed that trucks are available at the start time of scheduling, so considering uncertainty in the arrival time of receiving trucks is suggested. Clearly, considering this assumption adds complexity to the problem.

Data Availability

The data that support the findings of this study are available from the corresponding author, upon reasonable request.
Conflicts of Interest

The authors declare that they have no conflicts of interest.

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