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Research Article

Rolling Supply Chain Scheduling considering Suppliers, Production, and Delivery Lot-Size

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Supply chain management and integration play a key factor in contemporary manufacturing concept. Companies seek to integrate itself within a cooperative and mutual benefiting supply chain. Supply chain scheduling, as an important aspect of supply chain management, highly emphasizes on minimizing stock costs and delivery costs. Most previous researches on supply chain scheduling problems assume make-to-order production, which includes delivery cost in lot-size. This practice simplifies the complexity of the problem. Instead, this research discusses make-to-contract production, where the supply chain has a rolling planning horizon that changes according to contracts. Within a planning horizon, two types of interval are defined. The first is frozen interval, in which the manufacturing decision cannot be changed. The second is free interval, where schedules can be adjusted depending on new contracts. This research aims to build a robust rolling supply management schedule to satisfy customers' needs, by considering supplier, production, and delivery lot-size simultaneously. The objective is to effectively decide a combination of supplier, production, and delivery lot-size that minimizes total cost consisting of supplier cost, finish good stock cost, and delivery cost. Based on the concept, this study designs a problem-solving process that combines the methods of rolling planning horizon and genetic algorithm. Delivery size (DS), finish good stock (FS), and early delivery cost (ED) are the three methods applied; each will provide a guideline to produce a feasible solution. By further considering the fluctuations in practical needs and performing an overall evaluation, a robust and optimal supply chain scheduling plan can be decided, including the optimal lot-sizes of supplier, production, and delivery. In the effectiveness test which considers 3 types of customer demands and 11 types of company cost structures, the simulated data test results suggest that the proposed methods in this study have excellent performance.

1. Introduction

In contemporary manufacturing industries, it is a common practice for firms to operate as a part of a supply chain. Therefore, supply chain management and production-sales integration are an essential topic for managers. Without appropriate supply chain management and planning, unnecessary costs may occur and result in wasting resources. However, it is highly possible to lower operating costs of firms while satisfying customer demands with proper supply chain management and supply chain scheduling. Meanwhile, the efficiency and profitability of the supply chain members can be greatly improved. The costs one should consider when doing supply chain scheduling come from several sources including material purchase, production, goods inventory, and transportation, which can be minimized through optimal supply chain scheduling.

Generally, a supply chain network often consists of a series of participants that play roles in the supply chain development. These participants, for instance, can usually be classified as four main roles: producers of raw materials, product-making factories, centers of distributing products, and customers. In previous supply chain scheduling studies, make-to-contract production is less discussed. A make-to-contract production means a producer signs a contract with its customer such that, within a certain period of time,

Date	1	2	3	4	5	6	7	8	9	10	11	12	…	t
PH	PH1													
Demand	Frozen interval									Free interval				
Customer A	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2^*	$A_3)$	$(A_1$	A_2^*	$A_3)$	…	
Customer B	$(B_1$	B_2	B_3	$B_4)$	$(B_1$	B_2^*	B_3	$B_4)$	$(B_1$	B_2	B_3^*	$B_4)$	…	
Customer C	$(C_1$	$C_2)$	$(C_1$	$C_2)$	$(C_1$	$C_2)$	$(C_1$	$C_2^*)$	$(C_1$	$C_2)$	$(C_1^*$	$C_2)$	…	
⋮														
Customer a	$(n_1$	n_2	$n_3)$	$(n_1$	n_2	$n_3)$	$(n_1$	n_2	$n_3)$	$(n_1$	n_2	$n_3)$	…	
Decision	$(P_1$	P_2	P_3	P_4	P_5	P_6	P_7	P_8	$P_9)$	$(P_1$	P_2	$P_3)$	…	

Demand updated and rescheduled →

Date	1	2	3	4	5	6	7	8	9	10	11	12	…	t
PH	PH2													
Demand	Frozen interval									Free interval				
Customer A	$(A_1^*$	A_2	$A_3)$	$(A_1$	A_2	$A_3^*)$	$(A_1$	A_2	$A_3)$	$(A_1$	A_2	$A_3)$	…	
Customer B	$(B_1^*$	B_2	B_3	$B_4)$	$(B_1$	B_2	B_3	$B_4)$	$(B_1$	B_2	B_3	$B_4)$	…	
Customer C	$(C_1$	$C_2)$	$(C_1$	$C_2)$	$(C_1$	$C_2)$	$(C_1$	$C_2^*)$	$(C_1$	$C_2)$	$(C_1^*$	$C_2)$	…	
⋮														
Customer a	$(n_1$	n_2	$n_3)$	$(n_1$	n_2	$n_3)$	$(n_1$	n_2	$n_3)$	$(n_1$	n_2	$n_3)$	…	
Decision	$(P_1^*$	P_2^*	P_3^*	P_4^*	P_5^*	P_6^*	P_7^*	P_8^*	$P_9^*)$	$(P_1^*$	P_2^*	$P_3^*)$	…	

∗Demands Updated

Demand updated and rescheduled → • • •

Figure 1: Rolling customer demands.

demands of customer are fully satisfied. The advantage of this type of cooperation is the possibility of establishing a long-term and predictable relationship between two sides. However, even with make-to-contract cooperation, in some cases customer demands may change due to reasons such as fluctuation in market prices and new generation of product introduced. Accordingly, customers may request extra products to be provided. Since such changes are difficult to predict, this study considers it as a random demand change and deal with it as a rolling planning horizon. It means after a supply chain schedule is created and executed for a certain amount of time, the schedule will be rescheduled which takes new demands into consideration, as illustrated in Figure 1.

Figure 1 shows a supply chain considered in this study, where raw materials are provided by supplier and demands placed by customers. A producer must place orders to suppliers beforehand for suppliers to prepare and deliver. A producer deals with multiple customers simultaneously, and each customer has a make-to-contract demand. Demands may randomly alter due to demand side request. Take customer A for example; its contract with the producer cycles every 3 periods. Assume a rolling planning horizon consists of 12 periods. The first 9 periods are called frozen interval, where production plan cannot be altered. In order to respond to demand changes, the last 3 periods are set as free interval, where production plan can be revised according to new demands. The rolling and rescheduling method allows efficient revision of a production plan such that the new demands can be met. To make the problem more realistic, this study takes material purchase lot-size, production lot-size, and delivery lot-size into consideration. The objective is to achieve a supply chain schedule that minimizes total supply chain costs, by optimizing material ordering, production, and delivery decisions. In this premise, this study aims to provide a robust production-sales plan or supply chain schedule that applies to most circumstances, in which producers can update the schedule whenever demands change until the whole schedule planning horizon ends.

2. Literature Review

Supply chain scheduling problems are quite complex and can be evaluated from multiple aspects. Efforts on researching supply chain scheduling can be summarized in four aspects. The first one is improvement of production environment assumptions to make it reflect the reality. For example, Zegordi et al. [1] solved a two-stage supply chain model with improved genetic algorithm. The supply chain model consisted of two stages: production and transportation. In the first stage (i.e., production), there are multiple suppliers which differ in production speed. In the second stage (i.e., transportation), there are multiple transport units with various capacity and speed. Note that each unit of product occupies transport capacity based on its characteristic. Neto et al. [2] transformed an outsourcing supply chain into a permutation flow shop and showed that an improved ant colony optimization metaheuristic algorithm can effectively solve this problem. Cakiciet al. [3] proved that an integrated supply chain that do both produce and transport is NP-hard, and they used genetic algorithm to obtain satisfactory solutions. In this environment, a manufacturer takes orders and produce them on single production line. The objective is to minimize weighted late delivery and transportation costs. Products are delivered to customers by trucks with limited capacity. Each order is given specific number of products, due date, processing time, and weight. It makes the problem closer to reality and thus provided more insights for decision-makers. Tang et al. [4] further discussed a three-tier supply chain scheduling networked manufacturing problem. The supply chain consisted of a design center, a manufacturing center and multiple demand nodes. There are several transportation methods; each takes different time and cost. An improved ant colony optimization metaheuristic algorithm was proposed in order to find an optimal solution.

The second aspect is considering new constraints of the problem. It is clear to see from the literature that batch or lot-size problem is repeatedly discussed in company practices because of its wide application in manufacturing. Huang [5] studies a job shop scheduling problem with lot-size. Holding cost, machine idle, and transportation cost are performance measurements. The results showed that holding costs and machine idle are negatively related to lot-size, where transportation cost is positively related to lot-size. Lot-size has diminishing marginal returns to profit. This suggests that proper lot-size can effectively reduce total cost. Gicquel and Minoux [6] discussed a multiproduct valid inequalities for the discrete lot-sizing and scheduling problem. The objective of the problem is to minimize conversion cost and is solved with improved genetic algorithm. Schütz and Tomasgard [7] studied the impact of flexibility on operational supply chain planning. The flexibility of production, transportation, and decision making is constrained by uncertain demands of customers. Rolling scheduling technique is applied in order to cope with changing demands. A total of one-year production plan is established by using rolling scheduling technique. For each iteration, a four-week plan is made, with confirmed demand in the first week and forecasted demands in the following three weeks. They used meat product industry as an example and pointed out the importance of flexibility when demands are uncertain. It is important to take more realistic constraints into consideration, since it improves the contribution of the study on both practical applications and academic development.

The third aspect is pursuing new types of performance measures. The development of supply chain scheduling studies is prone to take multiple criteria into consideration because of such characteristic. For instances, Beamon [8] proposed several performance measurements for a supply chain system, which can be used as evaluation criteria for supply chain scheduling problems. Yao and Liu [9] built a dynamic mathematical model to solve the tradeoff problem between mass customization and customer demand. They proved that the proposed model, combined with an improved ant colony optimization metaheuristic algorithm, can effectively deal with the tradeoff problem. The fact that tradeoff exists among objectives of a supply chain scheduling problem is obvious and makes the problem more realistic. Nedaei and Mahlooji [10] conducted a study on joint multiobjective master production scheduling and rolling horizon policy analysis in make-to-order supply chains according to the classification of Sahin et al. [11] on rolling horizon planning in supply chains. A two-stage supply chain is designed, and two production decision methods are applied to make a rolling schedule. The first method is master production scheduling, and the second method is advanced order commitment. The objective is to optimize the robustness of the schedule and minimize holding cost. Scheduling nowadays is quite different from the past because new technologies invent and new issues rise as time progresses. This is the reason why studies have to consider more objectives such as carbon emission and power consumption in addition to classical measurement such as makespan and lateness.

The fourth aspect is developing new models to solve the problems. Choudhary and Shankar [12] proposed a goal programming model for joint decision-making of inventory lot-size, supplier selection, and carrier selection. Customers can buy identical products from multiple suppliers at any time. The problem is multiobjective that includes returned product, transportation cost, and late delivery cost and is solved with a multiobjective integer programming model. Selvarajah and Zhang [13] took each manufacturer as a single machine and minimized holding and delivery costs of a supply chain scheduling problem with genetic algorithm. Karimi and Davoudpour [14] considered multifactory in a supply chain scheduling with batch delivery. Goods between each stage were delivered by trucks. The main objective is to minimize transportation cost and late delivery penalty. A branch and bound method was applied to solve this problem. Bahrampour et al. [15] presented a three-phase multiproduct supply chain network model. An improved genetic algorithm is used to solve the problem, in which its encoding method is based on priority-centered encoding. Their experiments provide both heuristic solutions generated by genetic algorithm and mathematical programming solutions returned from LINGO, a package software. These studies all indicate that a multistage model has superior performance compared to single-stage or two-stage models. Gould et al. [16] developed a material flow modelling tool for resource efficient production planning in multiproduct manufacturing systems. The tool provides decision-makers an efficient approach to improve the quality of product allocation, the material flow, and resource utilization. Felfel et al. [17] focused on a multiproduct, multiperiod, and multisite supply chain planning problem under demand uncertainty. A multistage stochastic linear programming model is proposed to maximize the expected profit. The decisions to be made in the model comprise the production amount, the inventory, and backorder sizes as well as the quantity of products to be transported between upstream and downstream plants and customers in each period. The solutions of their multistage stochastic model outperform the deterministic and the two-stage stochastic models. Developing new models to solve complex scheduling problems has been frequently observed in the literature. It is the primary method to enhance the effectiveness and efficiency of a schedule. As we can see from the literature, the main methods used to solve the targeted problems include heuristic algorithms, branch and bound, and mathematical models.

From the above review, one can see that most researches focus on supply chain scheduling rarely considering production lot-size and transportation lot-size simultaneously. While dealing with lot-size production and make-to-contract production problems, applying rolling scheduling techniques can often obtain satisfactory performance. From the previous research, the possibility of achieving good result if one chooses to apply rolling schedule when dealing with lot-size problems is statistically higher. There is a niche that previous researches may have yet to explore. Therefore, this study takes make-to-contract production, lot-size in supplier, production, and transportation into consideration and aims to construct optimal and robust supply chain schedules by using rolling scheduling technique and genetic algorithm. The result is believed to benefit both academically and industrially.

3. Problem Definition

In this section, the proposed supply chain schedule problem is defined mathematically. At the same time, an integer programming model is formulated, which can be applied to search for the best solutions for the proposed supply chain scheduling problem. The supply chain in this study is a three-stage model with one supplier in the first stage, one manufacturer in the second stage, and multiple customers in the third stage. Supplier is subject to a setup time before delivering materials. Lot-size applies to supplier, production, and transportation. Customers are assumed to have the same unit transportation cost because of two reasons. First, the delivery services are conducted under a contract, and the delivery cost is based on the number of trucks sent. Second, customers of the supply chain are assumed to locate in a relatively close area, where individual difference in delivery costs can be omitted. The same reason also goes for the assumption that the delivery arrives the same day the goods are sent. Material transportation costs have not been considered because they are included in the costs of material as a term in the contract. The storage capacity has no limit because the manufacturer is assumed to be a relatively small company compared to the scale of the whole supply chain, and rent storages are always available for the right price. The objective is to minimize lot-size costs occurring from conducting supplier, production, and transportation lot-sizing. For the target supply chain, the goal is to establish a 360-day rolling schedule. For every 15 days, a 30-day partial supply chain schedule will be generated. The integer programming model that describes the target supply chain scheduling problem and its notations are defined as follows.

3.1. Notation

T = total span of a supply chain schedule (T=360)

t = time of schedule, t = 0,1,. . .,360

m = actual number of trucks sent

R_q^t =material inventory at the end of time t

R_p^t =material purchase at time t

R_c^t =material consumption at time t (i.e. Goods produced at time t)

P_q^t =goods inventory at the end of time t

P_d^t =goods delivered at time t

V_i^t =goods delivered by truck i at time t

c_1 =material inventory cost per unit

c_2 =goods inventory cost per unit

c_3 =goods transportation cost per unit

c_4 =early delivery cost per unit

A = lot-size of material purchase

B =lot-size of production

D^t = number of goods demanded by customers at time t

E^t = number of early delivered goods at time t

S_q = maximum material purchase capacity

S_P = maximum goods production capacity

S_D = maximum goods delivery capacity

3.2. Mathematical Model

Objective

$$\min c_1 \sum_{t=1}^{T} R_q^t + c_2 \sum_{t=1}^{T} P_q^t + c_3 \times m + c_4 \times \sum_{t=1}^{T} E^t \tag{1}$$

Equation (1) is the objective function of the mathematical model, consisting of four types of costs. $c_1 \bullet \sum_{t=1}^{T} R_q^t$ is the total material inventory cost. $c_2 \bullet \sum_{t=1}^{T} P_q^t$ is the total goods inventory cost. $c_3 \bullet m$ is the total transportation cost. $c_4 \bullet \sum_{t=1}^{T} E^t$ is the total early delivery cost.

Constraints

$$R_q^t = R_q^{t-1} + R_p^t - R_c^t, \quad \forall t \in \{1, 2, \ldots, 360\} \tag{2}$$

$$P_q^t = P_q^{t-1} + R_c^t - P_d^t, \quad \forall t \in \{1, 2, \ldots, 360\} \tag{3}$$

$$E^t = E^{t-1} + P_d^t - D^t, \quad \forall t \in \{1, 2, \ldots, 360\} \tag{4}$$

In (2) the inventory of material at time t equals the sum of material inventory at time (t-1) and the number of material purchased at time t, minus the number of material consumed at time t. In (3) goods inventory at time t equals the sum of goods inventory at time (t-1) and number of goods produced at time t, minus the number of goods delivered to customers at time t. In (4) the early delivered number of goods at time t equals the early delivered number of goods at time (t-1) plus the number of goods delivered at time t minus the number of goods customers demanded at time t.

$$\sum_{t=1}^{T} D^t \le \sum_{t=1}^{T} P_d^t \tag{5}$$

$$\sum_{t=1}^{T} P_d^t \le \sum_{t=1}^{T} R_c^t \tag{6}$$

$$\sum_{t=1}^{T} R_c^t \le \sum_{t=1}^{T} R_p^t \tag{7}$$

In (5) the total number of goods customers demanded is less than or equal to the total number of goods delivered to customers. In (6) the total number of goods delivered to customers is less than or equal to the total number of goods produced. In (7) the total number of goods produced is less than or equal to the total number of materials purchased.

$$R_p^t \in nA, \quad \frac{S_q}{A} \geq n \geq 0, \ \forall t \in \{1, 2, \ldots, 360\} \tag{8}$$

$$R_c^t \in nB, \quad \frac{S_p}{B} \geq n \geq 0, \ \forall t \in \{1, 2, \ldots, 360\} \tag{9}$$

In (8) the number of material purchased is a multiple of A, because the lot-size of material purchased cannot be further divided. In (9) the number of goods produced is a multiple of B, because the lot-size of goods produced cannot be further divided.

$$P_d^t = \sum_{i=1}^{m} V_i^t, \quad \forall t \in \{1, 2, \ldots, 360\} \tag{10}$$

In (10) the total number of goods delivered at time t is equal to the sum of goods delivered by each truck at time t.

4. Problem Solving

This study proposes a procedure that combines rolling scheduling and genetic algorithm. The initial solutions for genetic algorithm are generated with 3 dispatching rules developed by this study and will be explained in the following section. Schedules are then generated heuristically by applying genetic algorithm according to the needs for the planning horizon (PH). In the case of this study, the planning horizon is 30 days, and the whole schedule span is 360 days. Every 15 days, a new schedule is generated for the planning horizon to deal with the changes in customer demands. Within the planning horizon, there are two types of interval. The first type of time interval that includes the first 15 days is called frozen interval (FI). The schedule of this interval is determined in the last iteration and cannot be rescheduled. The second type of time interval includes the last 15 days in a planning horizon and is called free interval. The supply chain schedule in a free interval can be rescheduled according to updated customer demand. The rescheduling procedure repeats until the end of the scheduling span.

4.1. Solving Procedure. The solving procedure is illustrated in Figure 2. First, the customer demand is decided by contracts between the manufacturer and customers. The planning horizon and frozen interval are given. The customer demands are updated randomly to simulate fluctuations in demands. Next, genetic algorithm is initiated by applying DS, FS, and ED rules and randomly generated schedules. The fitness of these initial schedules is first evaluated; then they are improved by genetic algorithm process (i.e., selection, mutation, and crossover mechanisms) until the stopping criteria is met. The encoding method is referred to in [15]. Note that these schedules are only partial schedules on the planning horizon (i.e., a 30-day schedule). The proposed solving procedure will end when the schedule span of 360 days ended and all customer demands are satisfied.

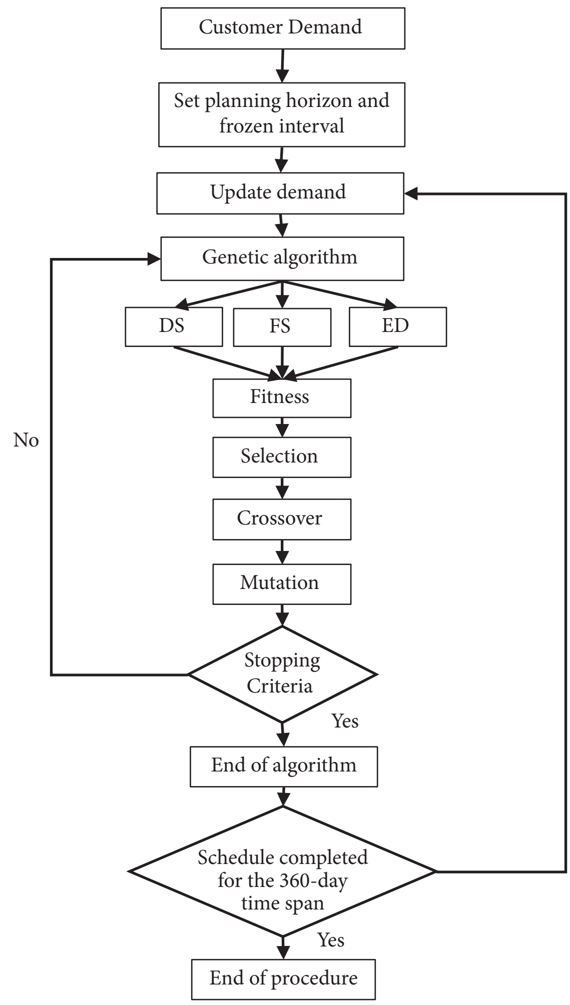

Figure 2: Solving procedure.

4.2. Measuring Criteria. The measuring criteria of the supply chain schedule in this study can be defined as follows.

$$PIP = 1 - \left(\frac{RHP - PI}{PI} \right) \tag{11}$$

where *PIP* stands for perfect information proximity, *PI* is the optimal solution obtained with perfect information, and *RHP* stands for an optimal solution obtained with rolling horizon planning.

In Eq. (11), *PI* is an optimal solution obtained when all future demands are known and forecasted (i.e., the status of perfect information). *RHP* is an optimal solution where information is partially transparent, which is the case in this study. Therefore, the higher the *PIP* is, the more effective and successful the proposed procedure is in dealing with the three-stage supply chain scheduling problem with lot-size.

To further elaborate the concept of *PI*, consider a planning horizon that equals the schedule span (i.e., $PH = T$), in which all demands within the horizon are determined and do not change. Under such condition, optimal solutions with minimized sum costs can easily be obtained by using the

T	1	2	3	4	5	6	7	8	9	10	11	12
D^t	$2(D^1)$		$4(D^2)$				$6(D^3)$					
P_d^t	$3(P_d^1)$			$3(P_d^2)$			$6(P_d^3)$					
R_c^t	$6(R_c^1)$						$3(R_c^2)$			$3(R_c^3)$		
R_p^t	$6(R_p^1)$						$3(R_p^2)$			$3(R_p^3)$		

Figure 3: A feasible solution obtained with DS rule ($S_p = 3$, $S_D = 3$, A=3, B=3).

T	1	2	3	4	5	6	7	8	9	10	11	12
D^t	$2(D^1)$		$4(D^2)$				$6(D^3)$					
P_d^t	$6(P_d^1)$						$3(P_d^2)$			$3(P_d^3)$		
R_c^t	$6(R_c^1)$						$3(R_c^2)$			$3(R_c^3)$		
R_p^t	$6(R_p^1)$						$3(R_p^2)$			$3(R_p^3)$		

Figure 4: A feasible solution obtained with FS rule ($S_p = 3$, $S_D = 3$, A=3, B=3).

mathematical programming model illustrated in Section 3. However, perfect information is quite rare the case in real production environment, and customer demands cannot be completely forecasted. Therefore, *PIP* is developed and used as a measurement for effectiveness to evaluating the proposed procedure in solving the specific rolling supply chain scheduling problem of this study.

4.3. Dispatching Rules. This study developed three dispatching rules based on the aspects of costs. These rules are delivery lot-size rule (DS), finished goods stock rule (FS), and early delivery cost rule (ED). These dispatching rules provide good initial schedules for genetic algorithm to iteratively improve and produce an optimal supply chain schedule plan with robust decisions on material purchasing, producing, and goods delivering. The three dispatching rules are explained and demonstrated as follows.

4.3.1. Delivery Lot-Size Rule. The aim of DS rule is transportation cost minimization. With DS rule, each truck will not depart before its full capacity utilized. This can fully utilize transportation capacity and minimize the number of trucks required to deliver finished goods. A partial supply chain schedule using DS rule is illustrated in Figure 3. Note that, for illustration purpose and as a term of contract-based scheduling, D^t, R_c^t, and R_p^t are predetermined. The value of $S_p = 3$, $S_D = 3$, $A = 3$, and $B = 3$ is set for illustrative purpose, thus displaying the difference among 3 dispatching rules clearly. In Figure 3, in order to minimize the number of trucks delivered, the trucks will wait until its full before they depart. The result as shown in Figure 3 is a unit of early delivered good of P_d^1.

4.3.2. Finish Goods Stock Rule. The goal for FS rule is goods inventory cost minimization. FS rule keeps goods inventory minimized by delivering as many goods produced at present period as possible to customers. Figure 4 shows a feasible partial schedule established by using FS rule. As we can see in Figure 4, for the purpose of minimizing goods inventory costs, all goods produced will be delivered to customers. Therefore, the result is 4 units of early delivery costs generated by the decision of P_d^1.

4.3.3. Early Delivery Cost Rule. The objective of ED rule is early delivery cost minimization. The number of goods delivered in each period follows the number of goods that customers demand. ED rule ensures that the early delivery costs are minimized. A feasible schedule is obtained by using ED rule, shown in Figure 5. In order to minimize early delivery costs, the manufacturer will only produce and deliver the exact units customers demand at a certain time period. However, decisions P_d^1 and P_d^2 result in the waste of delivery capacity (i.e., trucks are not fully loaded).

4.4. Example. An example supply chain problem is given in this section to illustrate how the proposed solving procedure deal with the supply chain scheduling problem. The parameters and customer demands are displayed in Tables 1 and 2.

In Table 1, the lot-size constraints of material purchasing and goods production, production capacity and transportation capacity per truck, unit costs of material holding, goods holding, goods delivery, and early delivery are given. Because these values for the parameters are only applied to an illustrative example given in this section, the values are designed to highlight the tradeoff relations among the objectives and the differences among 3 proposed dispatching rules. To further elaborate these parameters, quantity of material purchases can only be the multiple of 5 (e.g., 5, 10, 15, and 20). Similarly, the quantity of goods produced in each decision can only be 3 or 6. Each transportation unit (e.g., trucks, trains, and ship

T	1	2	3	4	5	6	7	8	9	10	11	12
D^t	$2(D^1)$		$4(D^2)$				$6(D^3)$					
P_d^t	$2(P_d^1)$		$4(P_d^2)$				$6(P_d^3)$					
R_c^t	$6(R_c^1)$						$3(R_c^2)$			$3(R_c^3)$		
R_p^t	$6(R_p^1)$						$3(R_p^2)$			$3(R_p^3)$		

FIGURE 5: A feasible solution obtained by using ED rule ($S_p = 3$, $S_D = 3$, A=3, B=3).

TABLE 1: Parameters.

Constraints		Supply chain related costs		
	Value		Per unit	Sum costs
Material purchasing lot-size	A = 5	Material holding cost	$c_1 = 10$	$c_1 \bullet \left(R_q^{t-1} + R_p^t - R_c^t\right)$
Production lot-size	B = 3	Goods holding cost	$c_2 = 10$	$c_2 \bullet \left(P_q^{t-1} + R_c^t - P_d^t\right)$
Production capacity	$S_P = 6$	Goods delivery cost	$c_3 = 20$	$c_3 \bullet (P_d^t / S_D)$
Transportation capacity	$S_D = 2$	Early delivery cost	$c_4 = 10$	$c_4 \bullet (E^{t-1} + P_d^t - D^t)$

cargos) can take at most 2 units of goods at one time (i.e., m = P_d^t/S_D). The cost of every unit of material or finished good hold in storage is 10 units of expense. Each finished good delivered to customer earlier than the contract stated costs 10 units of expense. Each unit of transportation (e.g., trucks, trains) costs 20 units of expense.

The initial demand during the period of 10 days for three customers is given as (2, 0, 2, 0, 2, 0, 2, 0, 2, 0), (1, 1, 1, 1, 1, 2, 2, 2, 2, 2), and (1, 2, 3, 2, 1, 1, 2, 3, 2, 1). Initial demands may change due to several factors such as fluctuation in the market price or announcement of new government regulation. Therefore, Table 2 shows the alternated demands and aggregated demand for three customers.

The proposed procedure first generates a 10-day schedule. In the rolling planning process, every 5 days the customer demand will be updated, and the supply chain schedule will be rescheduled in order to cope with the changing customer demand. The setup time for suppliers is also 5 days. Note that this setting simplifies the problem, as in real situation the customer may emphasize its demand and will not agree to take suppliers' constraints into consideration (e.g., consider a supply chain where customer demand updates every 3 days and the setup time of supplier is 5 days). According to the customers' demand shown in Table 2, DS rule is applied to providing an initial solution as illustrated in Figure 6. The aggregate customer demand is (4, 5, 6, 6, 3, 3, 6, 5, 6, 3). The demand for the first 5 days is fixed, whereas the demand in the last 5 days is forecasted by considering make-to-contract demand of customers. This will form a 10-day schedule for the first iteration. After 5 days (i.e., the second iteration), a new schedule will be generated with both fixed and forecasted demands. This procedure is repeated until the schedule span ends. During this process, extra costs may occur due to changes in schedule. Therefore, this study proposes three dispatching rules originating from the aspects of 3 types of costs to making effective and efficient supply chain schedule.

Figure 7 shows the schedule generated by using the proposed solving procedure. The schedule is constrained by production capacity (S_P), transportation lot-size (S_D), material purchasing lot-size (A), and production lot-size (B) and cannot violate these constraints. Note that, for all periods of the schedule, the sum of material purchased is larger than or equal to the sum of goods produced at the same period, and the sum of goods produced is larger than or equal to the sum of goods delivered (i.e., supply must not be less than demand). This practice ensures a nondelay supply chain schedule. The factor of transportation lot-size and a fixed transportation cost generated by sending trucks are both taken into consideration. The costs generated in each stage of the supply chain are explained as follows.

(1) Material holding Cost. In this example, the number of material purchased is the multiple of 5 ($A = 5$). Therefore, the decision for $R_p^1 = 10$, even though only 6 units of goods are produced ($R_c^1 = 6$). The difference between the two decisions will generate a material inventory cost. The same situation applies to decisions $R_p^1, R_p^4, R_p^6, R_p^7, R_p^{10}$. In exchange, the material inventory cost the manufacturer has to bear with equals $c_1 \bullet (R_q^{t-1} + R_p^t - R_c^t)$.

(2) Goods Holding Cost. The decision of R_c^1 is restricted by production lot-size ($B = 3$) and production capacity ($S_P = 6$). In order to satisfy the customer demand D^1 in a nondelay premise, $R_c^1 = 6$ is the only feasible decision to make. However, in order to avoid taking early delivery cost, the transportation decision $P_d^1 = 4$ (i.e., two full loaded trucks sent to delivering goods to customers) is made, which means the difference between R_c^1 and P_d^1 will result in a finished goods inventory cost that equals to $c_2 \bullet (P_q^{t-1} + R_c^t - P_d^t)$. We can observe the same type of costs occurred in the decision of P_d^1 and P_d^6.

(3) Goods Delivery Cost. Each truck sent to delivering goods to customers generates delivery cost, whether it is fully loaded or half loaded. Take the decision of $P_d^2 = 5$ for example; if

Table 2: Customer demands.

	Date									
	1	2	3	4	5	6	7	8	9	10
Customer 1	2	2∗	2	3∗	2	0	3∗	0	0∗	2∗
Customer 2	1	1	1	1	1	2	3∗	2	2	2
Customer 3	1	2	3	2	0∗	1	3∗	3	2	1
Aggregate Demand	4	5	6	6	3	3	9	5	4	5

∗The demand of customer at the period has changed.

Date	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Freeze interval						**Free interval**			
D^t	4	5	6	6	3	3	6	5	6	3
P_d^t	4	5	6	6	3	3	6	6	6	2
R_c^t	6	3	6	6	3	3	6	6	6	3
R_p^t	10	0	5	10	0	5	5	5	5	5

Demand updated and rescheduled

Date	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
	Freeze interval						**Free interval**			
D^t	3	9	5	4	5	4	3	6	3	4
P_d^t	4	8	6	3	6	3	3	6	3	4
R_c^t	6	6	6	3	6	3	3	6	3	6
R_p^t	5	10	5	0	10	0	5	5	5	5

Figure 6: Supply chain schedule established by using DS rule.

the trucks are fully loaded, 6 units of goods will be delivered. However, in this case, only 5 units of goods are delivered in which one of the three trucks is only half loaded. This is the result of making the schedule meet customer demand and avoiding early delivery cost. This cost of goods delivery is calculated as $c_3 \bullet (P_d^t/S_D)$.

(4) Early Delivery Cost. The goods delivery decision $\mathrm{P}_\mathrm{d}^6 = 4$ results in one unit of early delivered goods because the customer demand at time $t = 6$ is $\mathrm{D}^6 = 3$. The early delivery cost can be calculated as $c_4 \bullet (E^{t-1} + P_d^t - D^t)$.

(5) Relations among Each Type of Costs. The above example suggests that tradeoff relations exist among each type of costs as a result of supply chain decisions. Material inventory cost is affected by decisions on material purchase and goods production. Goods inventory cost is affected by decisions on goods production and goods delivery. Early delivery and goods delivery costs are influenced by decisions on goods delivery. The tradeoff relations between all types of costs and how decision-making can affect them are illustrated in Figure 8.

Tables 3, 4, and 5 demonstrated initial schedules generated by applying DS, FS, and ED rules. The results achieved by using these three dispatching rules are summarized in Table 6.

Since the example given is relatively simple and small scale, the proposed dispatching rules can achieve very good results as we can see in Table 6. The *PIP* of DS and FS rules are 100%, which means they perform as well as if having perfect information has proved the effectiveness of the proposed methods. The ED rule is less effective, but with also very high *PIP* of 97.5%. This result suggests that the three dispatching rules we proposed can effectively provide very good initial solutions for the supply chain scheduling problem addressed in this study. To further verify our solving procedure, large scale instances with various types of demands and cost structures will be simulated and tested in the following section.

5. Computational Results

All programs run and tested in this study are written in C++ programming language, complied, and executed on a desktop PC with Intel(R)Xeon(R)CPU E3-1231 and 8GB RAM. Test data is generated with uniform distribution [10]. The integer programming model is written and solved with package software Lingo 7.0. The supply chain has one supplier, one manufacturer, and 5 customers. Moreover, there are 3 types of demands: high-changing, medium-changing, and low-changing, in which demands fluctuate within 50% (Type III), 30% (Type II), and 10% (Type I) of the maximum production

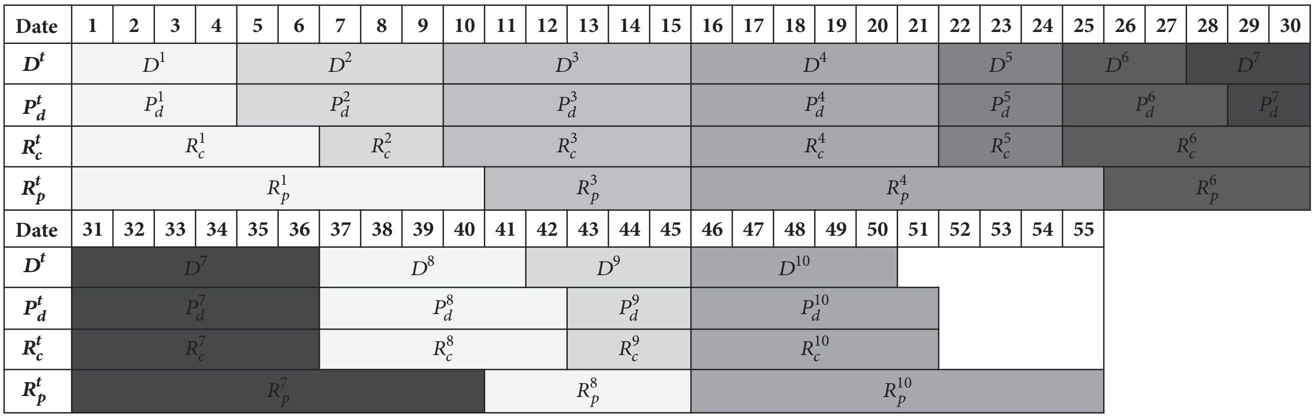

Figure 7: Supply chain schedule result of the given example.

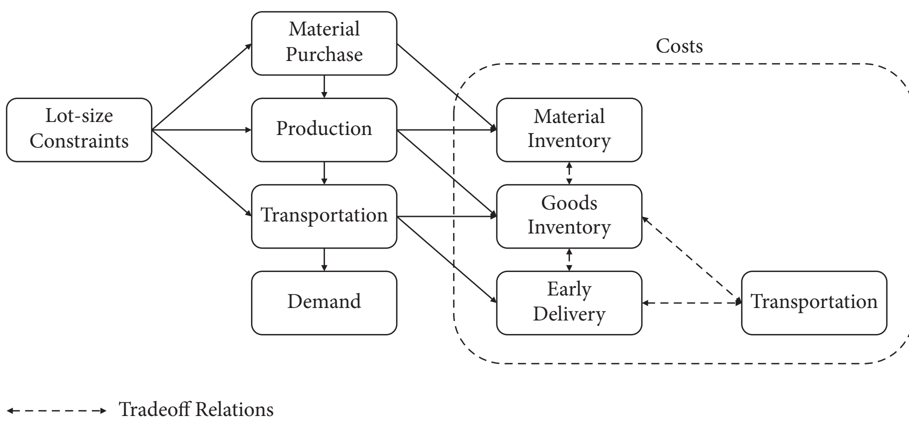

Figure 8: How decisions influence costs.

Table 3: DS rule initial schedule.

	Date									
	1	2	3	4	5	6	7	8	9	10
D^t	4	5	6	6	3	3	9	5	4	5
P_d^t	4	5	6	6	3	4	8	6	3	6
R_c^t	6	3	6	6	3	6	6	6	3	6
R_p^t	10	0	5	10	0	5	10	5	0	10

Table 4: FS rule initial schedule.

	Date									
	1	2	3	4	5	6	7	8	9	10
D^t	4	5	6	6	3	3	9	5	4	5
P_d^t	4	5	6	6	3	6	6	6	3	6
R_c^t	6	3	6	6	3	6	6	6	3	6
R_p^t	10	0	5	10	0	5	10	5	0	10

Table 5: ED rule initial schedule.

	Date									
	1	2	3	4	5	6	7	8	9	10
D^t	4	5	6	6	3	3	9	5	4	5
P_d^t	4	5	6	6	3	3	9	5	4	5
R_c^t	6	3	6	6	3	6	6	6	3	6
R_p^t	10	0	5	10	0	5	10	5	0	10

Table 6: Total costs results from using dispatching rules

	DS	FS	ED
Total costs	820	820	840
PIP	100%	100%	97.5%

Table 7: Cost structures.

Type of cost structure	$(c_1 : c_2 : c_3 : c_4)$
A	(1:1:100:1)
B	(2:1:100:1)
C	(1:2:100:1)
D	(1:1:100:2)
E	(2:2:100:1)
F	(2:1:100:2)
G	(1:2:100:2)
H	(1:1:200:1)
I	(2:1:200:1)
J	(1:2:200:1)
K	(1:1:200:2)

Table 8: Constant variables.

Parameters	
Production lot-size ($\boldsymbol{A}$)	100
Material purchase lot-size ($\boldsymbol{B}$)	40
Production capacity ($\boldsymbol{S_P}$)	280
Transportation capacity ($\boldsymbol{S_D}$)	50

capacity. The types of customer demands are applied to establish the supply chain schedule spans.

5.1. Test of Cost Structures. The cost structure is considered as an experiment variable, in order to ensure that the solving quality is not hindered in all types of cost structures and good decisions can be made. There are 11 types of cost structures from type A to type K that are applied in the effectiveness tests, where $[(c_1 : c_2 : c_3 : c_4)^A, (c_1 : c_2 : c_3 : c_4)^B, \ldots, (c_1 : c_2 : c_3 : c_4)^K]$ = [(1:1:100:1), (2:1:100:1), (1:2:100:1), (1:1:100:2), (2:2:100:1), (2:1:100:2), (1:2:100:2), (1:1:200:1), (2:1:200:1), (1:2:200:1), (1:1:200:2)]. Table 7 summarized the cost coefficients of each type of cost structure.

The constant variables in the experiments are production lot-size ($A = 100$), material purchase lot-size ($B = 40$), production capacity ($S_P = 280$), and transportation capacity ($S_D = 50$), as shown in Table 8. These values are decided by pretests to best illustrate the tradeoff characteristics of the proposed problem. If one of the cost coefficients is too high, it may cause an unbalance in the solving process (i.e., the algorithm will automatically put more emphasis on that type of cost and omit other types of costs). Similarly, the production lot-size, material purchase lot-size, production capacity, and transportation capacity are all decided by pretests in attempts to keep the solving process and results reasonable and realistic. The parameters of genetic algorithm used in our experiments are set after several rounds of pretests in order to best suit the proposed supply chain scheduling problem. According to pretests, the initial population size is 30, the crossover rate is 0.8, the mutation rate is 0.4, and the algorithm ends after 700 iterations.

5.2. Frozen Interval Length Test. This study first conducts a frozen interval sensitivity test to ensure that the proposed 3 dispatching rules DS, FS, and ED remain effective when dealing with various length of frozen interval. The test is conducted on 90-day supply chain schedules with different frozen length. As we can see in Table 9, all 3 rules have stable performances. In particular, FS performs quite well in all tests and has an average *PIP* of 97.7%. ED performs steadily with average *PIP* of 95%. DS does not perform well when FI = 10 but has good results when FI = 15 and FI = 20.

5.3. Effectiveness Test Results. In this section, effectiveness tests are conducted with the simulated data described before. The *PI* solutions are obtained with the integer programming model addressed in Section 3, in which customer demands are known and the solutions are optimal. The DS, FS, and ED solutions are obtained using genetic algorithm and respective dispatching rules.

As we can see in Tables 10, 11, and 12, the FS rule has the best performance in terms of robustness and *PIP*, followed by ED and DS. It suggests that planning a schedule from the perspective of minimizing goods inventory costs can generally obtain good results in all types of cost structures. We can also find that the DS rule does not present stable results constantly, giving extreme good or bad results. The ED rule generally gives stable results, but most of the time it is outperformed by the FS rule. Among 33 combinations of demand types and cost structure type, at least one approach generates a solution of *PIP* larger than 97% in 30 combinations. The types of demands do not significantly affect solution quality, which suggests the proposed approaches can achieve satisfactory solutions in all types of demands. The proposed approaches present an effective and efficient solution for supply chain decision-makers and integrators, because these approaches are easy to use and adapt to various types of demands and cost structures.

6. Conclusion

Production-sales integration and supply chain management are essential for contemporary manufacturing companies. Managers must keep in mind that the cooperation and integration as a whole in a supply chain system are much more competitive than a supply chain system where its members try to exploit each other. The cooperation of a firm with its suppliers and customers will create a virtuous cycle that can both reduce supply chain costs and improve customer service quality. That is the reason why supply chain scheduling receives so much attention recently. A supply chain scheduling model that takes all supply chain members and their activities into consideration can potentially reduce costs within the supply chain.

The variety of the supply chain problems is enormous. This study intends to combine research into practice, by

Table 9: Frozen interval length test result.

RHP				Total cost		
PH	FI	Reschedule frequency	*PI*	DS (*PIP*)	FS (*PIP*)	ED (*PIP*)
30	10	10	337,200	374,200 (89.0%)	351,200 (95.8%)	357,200 (94.1%)
30	15	15	337,200	342,200 (98.5%)	340,560 (99.0%)	351,200 (95.8%)
30	20	20	337,200	342,200 (98.5%)	343,200 (98.2%)	354,200 (95.0%)
Average				352,866.7	344,986.7	354,200

Table 10: Effectiveness test result (Type I).

	Approach						
	DS		FS		ED		*PI*
Type of cost structure	Average (*PIP*)	CPU time(s)	Average (*PIP*)	CPU time(s)	Average (*PIP*)	CPU time(s)	
A	1,501,221 (92.33%)	0.570	1,406,873.3 (99.00%)	0.534	1,437,226.7 (96.91%)	0.5.39	1,394,220
B	1,653,823.37 (90.75%)	0.581	1,523,820.00 (99.34%)	0.603	1,553,620.00 (97.37%)	0.443	1,513,820
C	1,747,723.33 (74.65%)	0.497	1,401,175.57 (99.50%)	0.432	1,557,0423.7 (88.32%)	0.667	1,394,220
D	1,594,111.12 (85.66%)	0.315	1,509,756.67 (91.71%)	0.542	1,425,403.33 (97.76%)	0.589	1,394,220
E	1,828,290.00 (79.23%)	0.667	1,523,822.24 (99.34%)	0.812	1,672,230.37 (89.54%)	0.978	1,513,820
F	1,731,940.58 (87.79%)	0.776	1,647,666.67 (93.25%)	0.530	1,555,225.76 (99.24%)	0.721	1,543,500
G	1,885,060.39 (73.11%)	0.738	1,509,754.31 (98.37%)	0.886	1,557,042.07 (95.19%)	0.519	1,485,600
H	2,560,828.18 (96.88%)	0.812	2,558,620.67 (96.96%)	0.788	2,631,531.30 (94.03%)	0.528	2,483,220
I	2,705,854.78 (97.34%)	0.738	2,676,412.07 (98.46%)	0.897	2,741,425.54 (95.99%)	0.657	2,635,820
J	2,761,420.32 (88.80%)	0.698	2,558,620.33 (96.96%)	0.437	2,719,949.56 (90.47%)	0.554	2,483,220
K	2,632,160.12 (96.78%)	0.733	2,656,241.97 (95.84%)	0.689	2,631,534.43 (96.81%)	0.536	2,550,140

taking realistic constraints in the proposed supply chain scheduling problem. For instance, most of the previous studies assume make-to-order production. The supply chain discussed in this study takes rolling make-to-contract production. Similarly, material purchase lot-size, production lot-size and transportation lot-size are constraints that frequently appear in real production environment, yet they are seldom addressed in the literature. The objective of minimizing material inventory cost, goods inventory cost, transportation cost, and early delivery cost under the above-mentioned constraints are a critical topic for managers nowadays.

This study aims to provide an effective and efficient procedure that minimizes material inventory cost, goods inventory cost, transportation cost, and early delivery cost of a supply

Table 11: Effectiveness test result (Type II).

Type of cost structure	DS Average (*PIP*)	DS CPU time(s)	FS Average (*PIP*)	FS CPU time(s)	ED Average (*PIP*)	ED CPU time(s)	*PI*
A	1,431,711.20 (97.52%)	0.633	1,408,010.77 (99.21%)	0.577	1,441,013.30 (96.85%)	0.661	1,397,010
B	1,661,410.40 (89.67%)	0.734	1,516,010.20 (99.32%)	0.612	1,536,810.67 (97.94%)	0.663	1,505,810
C	1,812,015.18 (70.29%)	0.734	1,408,104.59 (99.21%)	0.425	1,540,626.67 (89.72%)	0.318	1,397,010
D	1,603,374.59 (85.23%)	0.601	1,517,576.67 (91.37%)	0.512	1,441,013.74 (96.85%)	0.467	1,397,010
E	1,895,306.78 (63.28%)	0.855	1,516,010.11 (90.64%)	0.537	1,650,137.09 (80.97%)	0.399	1,386,260
F	1,771,825.94 (81.98%)	0.589	1,666,026.97 (89.03%)	0.576	1,536,815.18 (97.63%)	0.572	1,501,280
G	1,890,027.67 (71.63%)	0.879	1,517,573.55 (96.93%)	0.568	1,540,621.96 (95.36%)	0.354	1,472,360
H	2,541,518.82 (96.81%)	0.468	2,569,560.08 (95.67%)	0.568	2,614,010.68 (93.87%)	0.388	2,463,010
I	2,678,965.18 (94.48%)	0.587	2,642,463.40 (95.91%)	0.564	2,724,510.18 (92.68%)	0.235	2,538,700
J	2,787,013.33 (88.03%)	0.878	2,569,561.20 (96.77%)	0.268	2,720,340.23 (90.71%)	0.349	2,489,120
K	2,637,124.67 (98.23%)	0.489	2,663,420.33 (97.21%)	0.687	2,614,012.98 (99.12%)	0.385	2,591,200

chain, constrained by rolling make-to-contract customer demands and material purchase lot-size, production lot-size, and transportation lot-size. A realistic supply chain model is developed, where the manufacturer in the supply chain has to plan a 30-day schedule on a 360-day schedule span and reschedule every 15 days due to the changes in customer demands. This study develops a rolling scheduling procedure which is able to adjust schedules according to the changes of customer demands. This procedure combines 3 dispatching rules proposed in this study and genetic algorithm. It is proved to remain effective when the perfect information is not the case. These 3 dispatching rules DS, FS, and ED are developed based on the aspect of transportation cost, goods inventory cost, and early delivery cost, respectively. They are combined with genetic algorithm to provide heuristic solutions.

The effectiveness test on 3 types of demands and 11 types of cost structures proves that at least one of DS, FS, and ED rules can achieve more than 90% of *PIP* in all tested conditions. Out of 33 groups of testing, 30 groups return more than 95% of *PIP* by applying at least one of the DS, FS, and ED rules. The result suggests that the proposed solving procedure can adapt to any given conditions and generate high quality heuristic solutions in all circumstances.

For future researches, firstly, take transportation cost of purchasing material and suppliers material delivering lot-size constraint into consideration can make the supply chain model more realistic and suit for industrial practices. Secondly, the transportation and production decisions are made within the maximum capacity of the supply chain system in this study. In other words, late delivery is not considered in this study, which if added can make the model more realistic and complete in terms of matching real-world conditions.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors of this article declare that there are no conflicts of interests.

Table 12: Effectiveness test result (Type III).

Type of cost structure	DS Average (*PIP*)	DS CPU time(s)	FS Average (*PIP*)	FS CPU time(s)	ED Average (*PIP*)	ED CPU time(s)	*PI*
A	1,554,943.30 I(91.94%)	0.788	1,463,743.40 (98.28%)	0.738	1,487,941.70 (96.59%)	0.528	1,438,940
B	1,704,882.57 (88.28%)	0.698	1,586,791.13 (96.02%)	0.667	1,617,143.61 (94.03%)	0.533	1,526,010
C	1,758,044.03 (77.82%)	0.912	1,463,743.40 (98.28%)	0.713	1,634,839.24 (86.39%)	0.633	1,438,940
D	1,678,312.20 (83.36%)	0.615	1,586,817.11 (89.72%)	0.773	1,487,941.70 (96.59%)	0.545	1,438,940
E	1,876,511.58 (77.93%)	0.789	1,586,791.80 (96.78%)	0.498	1,753,161.26 (85.96%)	0.367	1,537,260
F	1,767,686.67 (85.30%)	0.699	1,581,065.00 (97.41%)	0.598	1,634,835.93 (93.92%)	0.447	1,541,090
G	1,796,983.10 (77.08%)	0.812	1,586,814.87 (91.45%)	0.598	1,487,941.17 (98.22%)	0.678	1,461,880
H	2,631,940.00 (98.10%)	0.713	2,655,440.00 (97.19%)	0.667	2,725,941.09 (94.46%)	0.547	2,582,940
I	2,786,344.90 (92.78%)	0.567	2,766,240.10 (93.55%)	0.671	2,861,142.58 (89.90%)	0.468	2,598,650
J	2,840,892.77 (90.01%)	0.776	2,655,442.24 (97.19%)	0.478	2,837,081.77 (90.16%)	0.456	2,582,940
K	2,715,081.59 (97.81%)	0.798	2,778,683.15 (95.41%)	0.699	2,725,943.33 (97.40%)	0.513	2,656,800

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References

[1] S. H. Zegordi, I. N. K. Abadi, and M. A. B. Nia, "A novel genetic algorithm for solving production and transportation scheduling in a two-stage supply chain," *Computers & Industrial Engineering*, vol. 58, no. 3, pp. 373–381, 2010.

[2] R. F. T. Neto and M. G. Filho, "An ant colony optimization approach to a permutational flowshop scheduling problem with outsourcing allowed," *Computers & Operations Research*, vol. 38, no. 9, pp. 1286–1293, 2011.

[3] E. Cakici, S. J. Mason, and M. E. Kurz, "Multi-objective analysis of an integrated supply chain scheduling problem," *International Journal of Production Research*, vol. 50, no. 10, pp. 2624–2638, 2012.

[4] L. Tang, K. Jing, and J. He, "An improved ant colony optimisation algorithm for three-tier supply chain scheduling based on networked manufacturing," *International Journal of Production Research*, vol. 51, no. 13, pp. 3945–3962, 2013.

[5] R.-H. Huang, "Multi-objective job-shop scheduling with lot-splitting production," *International Journal of Production Economics*, vol. 124, no. 1, pp. 206–213, 2010.

[6] C. Gicquel and M. Minoux, "Multi-product valid inequalities for the discrete lot-sizing and scheduling problem," *Computers & Operations Research*, vol. 54, pp. 12–20, 2015.

[7] P. Schütz and A. Tomasgard, "The impact of flexibility on operational supply chain planning," *International Journal of Production Economics*, vol. 134, no. 2, pp. 300–311, 2011.

[8] B. M. Beamon, "Measuring supply chain performance," *International Journal of Operations and Production Management*, vol. 19, no. 3, pp. 275–292, 1999.

[9] J. Yao and L. Liu, "Optimization analysis of supply chain scheduling in mass customization," *International Journal of Production Economics*, vol. 117, no. 1, pp. 197–211, 2009.

[10] H. Nedaei and H. Mahlooji, "Joint multi-objective master production scheduling and rolling horizon policy analysis in make-to-order supply chains," *International Journal of Production Research*, vol. 52, no. 9, pp. 2767–2787, 2014.

[11] F. Sahin, A. Narayanan, and E. P. Robinson, "Rolling horizon planning in supply chains: Review, implications and directions for future research," *International Journal of Production Research*, vol. 51, no. 18, pp. 5413–5436, 2013.

[12] D. Choudhary and R. Shankar, "A goal programming model for joint decision making of inventory lot-size, supplier selection

and carrier selection," *Computers & Industrial Engineering*, vol. 71, no. 1, pp. 1–9, 2014.

[13] E. Selvarajah and R. Zhang, "Supply chain scheduling at the manufacturer to minimize inventory holding and delivery costs," *International Journal of Production Economics*, vol. 147, pp. 117–124, 2014.

[14] N. Karimi and H. Davoudpour, "A branch and bound method for solving multi-factory supply chain scheduling with batch delivery," *Expert Systems with Applications*, vol. 42, no. 1, pp. 238–245, 2015.

[15] P. Bahrampour, M. Safari, and M. B. Taraghdari, "Modeling Multi-Product Multi-Stage Supply Chain Network Design," *Procedia Economics and Finance*, vol. 36, pp. 70–80, 2016.

[16] O. Gould, A. Simeone, J. Colwill, R. Willey, and S. Rahimifard, "A Material Flow Modelling Tool for Resource Efficient Production Planning in Multi-product Manufacturing Systems," in *Proceedings of the 48th CIRP International Conference on Manufacturing Systems, CIRP CMS 2015*, pp. 21–26, Italy, June 2015.

[17] H. Felfel, O. Ayadi, and F. Masmoudi, "A Multi-site Supply Chain Planning Using Multi-stage Stochastic Programming," in *Multiphysics Modelling and Simulation for Systems Design and Monitoring*, vol. 2 of *Applied Condition Monitoring*, pp. 289–298, Springer International Publishing, 2015.