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Pallet Scheduling Models Under Deterministic and Non-Deterministic Scenarios Using a Hybrid GA Method:

Pallet Scheduling Models

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ABSTRACT

This study examines the pallet scheduling problem considering random demands under the novel pallet operation mechanism by resources sharing among the pallet sharing system. Two nonlinear integer pallet scheduling models under deterministic and non-deterministic environment are formulated in terms of the pallet demand variable. To solve the pallet programming model, the hybrid genetic algorithm (HGA) integrating local search strategy is designed to derive the optimal pallet scheduling solution. Besides, the fixed sample size sampling strategy is employed to deal with the uncertain demand during the non-deterministic programming model, realized by the Monte Carlo simulation. The two models can assist decision makers arrange a scientific pallet scheduling solution under deterministic and non-deterministic atmosphere. Finally, the numerical case is implemented to testify the effectiveness of the two models and efficiency of the hybrid algorithms.

KEYWORDS

Fixed Sample Size Sampling Strategy, Hybrid GA, Monte Carlo Simulation, Pallet Scheduling, Random Demand

INTRODUCTION

Pallet, as one of the crucial ingredients in modern logistics system, has played significant role on efficiency improvement of transportation and distribution processes (Zhou et al. 2016, Ren and Zhang 2010a). The pallet is a portable, horizontal, rigid platform for goods storing, stacking, handling, and transporting in a unit load (Aldaz-Carroll and Raballand 2005, White and Hamner 2005). During the logistics plants, the prevailing adoption of cargo loading with pallet has reduced the intermediate handling operations, leading to the efficiency improvement and resources deployment (He et al. 2019a). Besides, the pallet contributes to the achievement of supply chain integration and logistics synergy. The pallet has been regarded as one of the key innovations of the twentieth century for material handling. The adoption of pallet innovation has improved the efficiency of logistics activities; however, the utilization rate of pallet is relative low in Chinese industrial plant due to the lack of pallet sharing mechanism innovation and pallet scheduling optimization (He et al. 2018). The pallet sharing alliance starts from the Europe, which assists to achieve the logistics cost reduction and resources sharing.

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Raballand and Aldaz-Carroll (2007) examined the influence of multiplicity of pallet standards on the logistics cost through case study, and results show that the pallet sharing alliance can improve cost reduction and operational efficiency.

As the effective improvement tool of pallet efficiency, the pallet sharing alliance or pallet pool system has been addressed in previous publications. The pallet sharing alliance is actually a cooperation union integrating the pallet manufacturer and the pallet renter, aiming at the resources sharing and cost reduction (He et al. 2019b). The pallet sharing alliance has been widely used in the modern logistics plant, such as the distribution center and warehouse plant (Zhou et al. 2020). The pallet scheduling solution is to determine the specific pallet volumes that pallet supplier provides for pallet customer with the minimized total operational cost within required time. To improve the utilization rate and pallet efficiency, the operation mechanism or structure of the pallet sharing alliance and pallet scheduling have been addressed by academic researchers and practical practitioners. Ren and Zhang (2010a) developed a pallet recovery model based on modified pallet pool system by pallet sharing, and the stochastic pallet recycling programming model by addressing the uncertainties of demands and transportation capability (Ren and Zhang 2010b). To achieve the sustainability and stability of the virtual pallet alliance, the mechanism of profit distribution using Raiffa model and the improved Shapley value is proposed to assist the specific allocation (He et al. 2018). Through the structure construction, operational mechanism and strategic organization of the pallet alliance, there emerged a vast majority of pallet innovation practice. LI et al. (2012) designed the mechanism of pallet profit distribution in the light of Shapley value considering income component of pallet rental firm alliance and the risk ability. Ren and Zhang (2011) developed a two stage stochastic chance constrained programming model, targeting the dispatch cost minimization considering uncertain factors, such as transportation capability and handling ability. To solve the stochastic programming model, the chance constrained approach is designed to convert the uncertain programming model to a deterministic model. In addition, the joint pallet scheduling problem is addressed by integrating inventory, manufacturing and transportation process, and a multi-scenario model is developed to optimize the pallet allocation under the pallet pool environment (Ren et al. 2014). In the pallet pool system, the pallet usage and operation efficiency could be improved by duty-cycle operation. The service route optimization (SRO) of pallet service center was studied to derive the optimal service path through VRP programming modeling, and a hybrid intelligent algorithm integrating stochastic simulation, neural network and immune clonal operation was designed to solve the formulated model (Zhou et al. 2016). To improve the pallet operation efficiency, advanced manufacturing technologies and information techniques are employed in the pallet pool system. Ren introduced a novel optimization model in terms of operations of a pallet pool with RFID-tagged pallets and non-tagged pallets. The non-linear programming model is formulated regarding the total operation cost minimization of a pallet pool as the optimization objective, including rent cost, transportation cost, distribution cost, maintenance cost, storage cost and punishment cost items (Ren et al. 2018). He et al. (2016) developed a multi-objective optimization pallet scheduling model by addressing the production, inventory and transportation capability constrained scenario, and a GA-based robust control is designed to solve the formulated model. From the above-mentioned references, we can found that many studies concentrated on the segmental research of pallet pool system, sharing mechanism and classical pallet scheduling problem. Besides, the uncertain factors have been widely considered in the pallet management practices, either for pallet scheduling or joint scheduling problem (Ni et al. 2015, Li et al. 2016).

Most of the previous publications pay much attention to the segmental study on traditional pallet system, and ignoring the novel management practice and the corresponding operations strategy investigation under the pallet sharing alliance scenario. In the existing pallet sharing system, generally speaking, most of the industrial practitioners shift their eyes on the pallet sharing alliance construction just from the viewpoint of pallets' lessors, while neglecting the other stakeholders involved in the system. This phenomenon leads to that we often pay too much attention to the responsibility of the pallet providers. Therefore, we present a strategic pallet operation under a novel pallet sharing system through pallet scheduling study.

There are two models formulated in this study under deterministic and non-deterministic demand scenarios. The objective function is to minimize the total cost of pallet scheduling in the deterministic model. To address the uncertainty in the industrial plant, the stochastic demand factor is also considered to reflect the real pallet operation in logistic system. The purpose of this study is to assist the industrial managers to find a pallet scheduling solution under the novel pallet sharing system. The contributions of this study are threefold. Firstly, a novel pallet sharing alliance is established through the introduction of the manufacturer and operator of pallets jointly. Secondly, we formulated a deterministic non-linear pallet programming model, and a hybrid genetic algorithm with local strategy is developed to derive the pallet scheduling solution. Thirdly, the stochastic programming model is developed to solve the non-deterministic programming model, and the hybrid GA is designed with Monte Carlo simulation. Besides, a numerical case is conducted to verify the effectiveness of the formulated model and the proposed algorithm.

The reminder of this paper is organized as follows. We present a novel pallet sharing alliance by introducing the pallet manufacturer in section 2. Then, two pallet scheduling programming models under deterministic and non-deterministic demand scenario are formulated and developed. To solve the nonlinear programming model, the hybrid genetic algorithm with local search strategy is designed in section 4. Besides, a numerical case is performed and presented to verify the formulated models. Finally, we end this paper with some conclusions.

THE SHARING PALLET ALLIANCE

The joint pallet sharing mechanism started from the Europe, and the sharing pallet assists to improve logistics efficiency and reduce transportation cost. Logistics union, as the powerful management philosophy, has been proven to be a great triumph on efficiency improvement and resources allocation, whose core connotation is the alliance formation under the assistance of contact. In the light of the philosophy of the logistics union, the pallet sharing alliance is proposed by introducing the pallet manufacturers to the pallet service platform, illustrated in Fig 1. The stakeholders of the novel pallet sharing alliance include pallet manufacturer, pallet operator and pallet customer etc. All these members can perform their rights and duties under established contracts.

Similar to the logistics alliance, the sharing pallet sharing alliance is a novel organization mode for efficiency improvement and resources sharing, consisting of various stakeholders of pallet activities. To ensure the success of the novel pallet sharing alliance, the following five processes need to be addressed including construction of pallet sharing alliance, business collaboration, service evaluation, profit distribution and the integrated pallet scheduling.

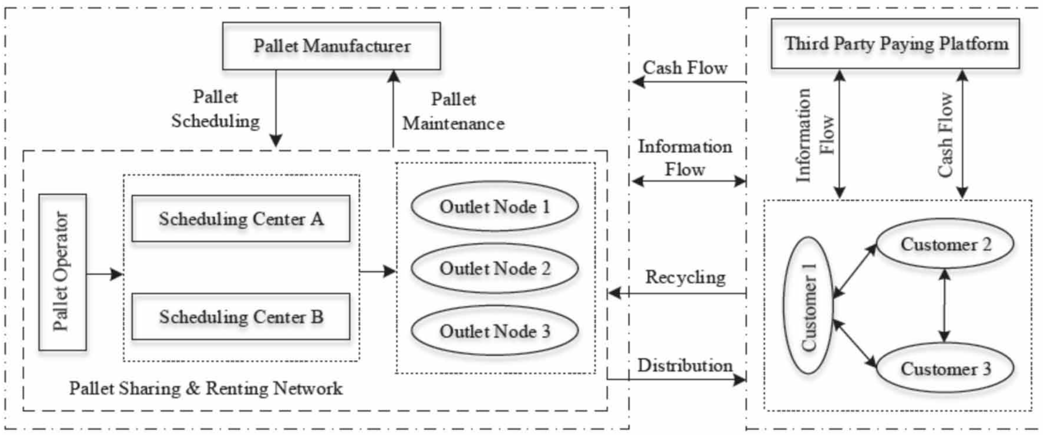
Programming Model Formulation

To deal with the pallet scheduling problem under novel pallet sharing alliance, the two programming models are formulated, first of which is deterministic model in precise environment, and the second of which is non-deterministic model by considering the uncertain characteristics of the customers' demands. Both of the two models have targeted the total cost of the pallet alliance scheduling as the optimization objective. The non-deterministic programming model achieved by stochastic nonlinear programming make the theoretical model more coincidence with the practical application in industrial plants.

Symbols and Notations

The used variables and their notations are presented in Table 1.

Figure 1. The novel pallet sharing alliance



Deterministic Programming Model Formulation

In the first deterministic model, we formulate a non-linear programming model to minimize the total scheduling cost, where the customers' demand is supposed to be a certain variable. The aim of this model is to determine the pallet amount vector under the capacity of the system.

Table 1. Variables and notations

Variable symbols	Notations
X_{ij}	Pallet amount from the supplier *i* to the customer *j*
C_{ij}	Transportation cost from the supplier *i* to the customer *j*
C_i	Inventory cost of the supplier *i*
PC_j	Penalty cost per unit when the customer *j* is not satisfied
ST_i	Inventory of the supplying provider *i*
ST_i^M	Maximum inventory capacity of the pallet supplier *i*
S_i	Capacitated supply amount by the pallet supplier *i*
TR_i	Transportation ability of the pallet supplier *i*
D_j	Pallet demand of customer *j*

$$\min TC = \sum_{i=0}^{m} \sum_{j=1}^{n} C_{ij} X_{ij} + \sum_{i=0}^{m} C_i ST_i \tag{1}$$

s.t.

$$\sum_{j=1}^{n} X_{ij} \leq S_i \tag{2}$$

$$\sum_{i=0}^{m} X_{ij} = D_j \tag{3}$$

$$ST_i \leq ST_i^M \tag{4}$$

$$ST_i = S_i - \sum_{j=1}^{n} X_{ij} \tag{5}$$

$$\sum_{j=1}^{n} X_{ij} \leq TR_i \tag{6}$$

$$C_{ij}, C_i, ST_i^M, ST_i, PC_j \geq 0 \tag{7}$$

Non-Deterministic Programming Model Formulation

To address the uncertainty of the demand variable, a two-stage stochastic programming model is formulated and developed to deal with the non-deterministic programming problem. The aim of this stochastic model is to derive the same decision variable that is the same with the deterministic model, also solving the stochastic factor. Therefore, a two-stage stochastic programming model is developed to deal with the non-deterministic programming model, formulated as follows:

$$\min TC = \sum_{i=0}^{m} \sum_{j=1}^{n} C_{ij} X_{ij} + \sum_{i=0}^{m} C_i ST_i + f \tag{8}$$

s.t.

$$\sum_{j=1}^{n} X_{ij} \leq S_{i} \tag{9}$$

$$ST_{i} \leq ST_{i}^{M} \tag{10}$$

$$ST_{i} = S_{i} - \sum_{j=1}^{n} X_{ij} \tag{11}$$

$$\sum_{j=1}^{n} X_{ij} \leq TR_{i} \tag{12}$$

$$C_{ij}, C_{i}, ST_{i}^{M}, ST_{i}, PC_{j} \geq 0 \tag{13}$$

The above-mentioned formula Eq. (8) aims at minimizing the total pallet scheduling cost, and f represents the optimal value of uncertain programming model. The constraints in Eq. (9) - Eq. (13) is similar to the deterministic programming model. The second-stage model is formulated as follows, where the demand variable is regarded as uncertain.

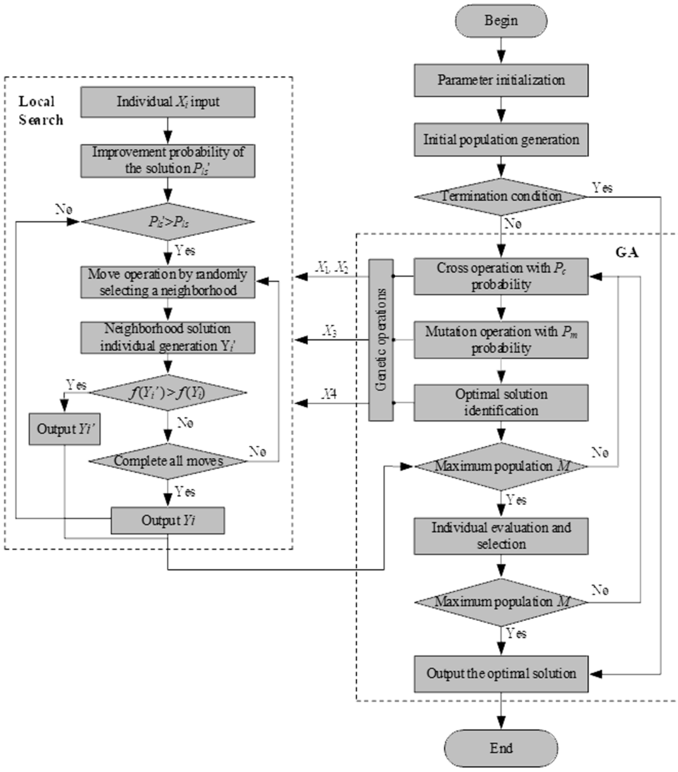
$$\min\ f = PC \sum_{j=1}^{n} s_{j} \tag{14}$$

$$\sum_{i=0}^{m} X_{ij} = \tilde{D}_{j} + s_{j} \tag{15}$$

HYBRID ALGORITHMD DESIGN

The pallet scheduling problem has been proved a NP-hard problem, and heuristic-based algorithms are most widely to resolve this issue (Zhou et al. 2017). The genetic algorithm (GA), prevailingly used in nonlinear programming model has been applied to deal with the deterministic pallet scheduling model. In addition, to improve the efficiency of the heuristic algorithm, the local search strategy is employed to strengthen the evolution (Zhou et al. 2018). The hybrid GA is designed and the detail steps of the algorithm are presented in the following Figure 2. As for the non-deterministic formulation model, the fixed sample size (FSS) sampling strategy is employed to deal with the uncertainty by Monte Carlo simulation steps.

Figure 2. The hybrid GA implementation steps



Chromosome Coding

GA is a heuristic algorithm which is implemented by genetic operations of the chromosome evolution. The practical solution is represented by numerical codes following some criteria. There are several coding modes including 0-1 coding, real number coding and sequence coding techniques (Fuli Zhou et al. 2019a, Fuli Zhou et al. 2019b, He et al. 2019a). In this study, the real-number coding method is applied based on the structure of the pallet scheduling solution. The chromosome is composed by a two-dimensional matrix, the row of which represents pallet supplier, and the column of which denotes the pallet customer, illustrated in Figure 3. The element x_{ij} denotes the pallet volume form supplier *i* to customer *j*.

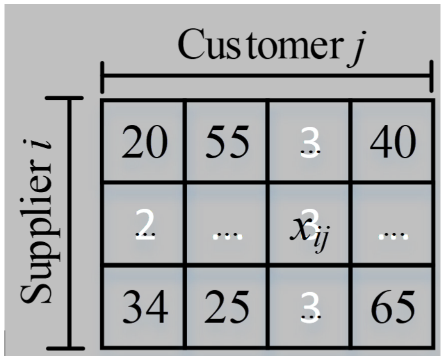
Fitness Function

The pros and cons of the pallet scheduling solution are judged by the specific value of the fitness function. The objective function of the formulated programming model is the total pallet scheduling cost, as Eq. (1) and Eq. (8) are shown. Therefore, the fitness function can be formulated as the following Eq. (16) shows.

$$fitness(x_{ij}) = {}^{1}\!/_{TC} \tag{16}$$

where *TC* is the total pallet scheduling cost calculated by Eq. (1) and Eq. (8).

Figure 3. Chromosome coding map of pallet scheduling solution



Genetic Operations

The optimal pallet scheduling solution is derived by genetic operations including selection, crossover and mutation operator. In this sub-section, the three genetic operations are defined through the adaptive genetic operators (Ni et al. 2015).

Selection operation

The selection operation aims at copying the good alternative individual to the next generation according to the fitness value of each individual. The individual P_i is drawn to stay in the next evolution with certain selection probability. Those individuals with higher fitness value will have higher possibilities to be copied to the next generation. It is noteworthy that the selection probability is an adaptively dynamic instead of a constant, which is calculated by the following Eq. (17).

$$p_s(P_i) = fitness_i(P_i) \Big/ \sum_{i=1}^{N} fitness_i(P_i) \tag{17}$$

where $p_s(P_i)$ is the selection probability of individual P_i being chosen to be copied.

Crossover and Mutation Operation

Different with the selection operation, the crossover and mutation operation among chromosomes enriches the pallet scheduling solution by generating new individuals. A higher crossover and mutation probability improves search ability of the heuristic algorithm, while leading to the loss of better genes. Therefore, the adaptive crossover and mutation operator are employed to calculate the genetic probability. The two-pint crossover operation and two-point mutation operation are adopted illustrated in Figure 4 and Figure 5. Besides, the adaptive crossover probability and mutation probability is calculated in Eq. (18) and Eq. (19).

$$P_c = \begin{cases} P_{c1} - \dfrac{(P_{c1} - P_{c2})(f' - f_{avg})}{f_{\max} - f_{avg}}, f' \geq f_{avg} \\ P_{c1}, \qquad\qquad\qquad\qquad f' \geq f_{avg} \end{cases} \tag{18}$$

Figure 4. Two-point crossover operation

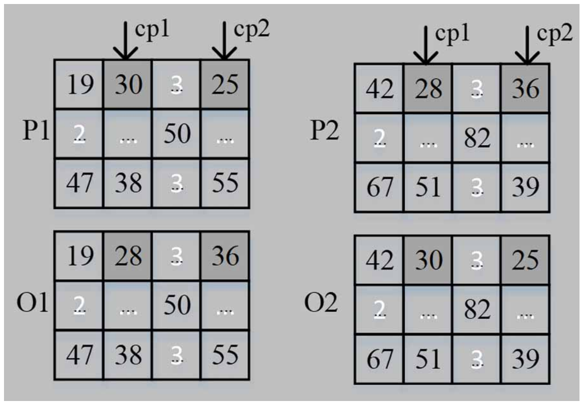
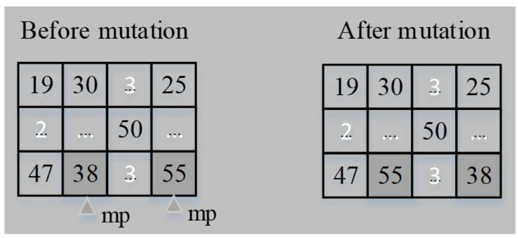


Figure 5. Two-point mutation operation



where P_c is the crossover probability; f_{avg} is the average fitness value of the population, and $f_{\max}$ is the optimal fitness value. Generally speaking, P_{c1} =0.9, P_{c2} =0.6.

$$P_m = \begin{cases} P_{m1} - \dfrac{(P_{m1} - P_{m2})(f_{\max} - f^{'})}{f_{\max} - f_{avg}}, f^{'} \geq f_{avg} \\ P_{m1}, \qquad\qquad\qquad\qquad f^{'} \geq f_{avg} \end{cases} \tag{19}$$

where P_m is the mutation probability, and suppose P_{m1} =0.1, P_{m2} =0.001.

Local Search Strategy

The GA is famous for its global search ability in nonlinear programming models. To improve the search capability of the hybrid algorithm, the local search strategy is employed to assist discover the optimum in different search spaces. According to the characteristics of the pallet scheduling problem, the neighborhood exchanging search structure is designed to perform the search operation. The gene in the chromosome solution is randomly selected, and the nearest solutions are chosen to be compared, which will be identified whether the alternative solution is better than the previous one (Fuli Zhou et al. 2019c, Lin Zhou et al. 2019). The LS strategy ends when all the neighborhoods are balanced as a result of finding a much better solution.

Fixed Sample Size (FSS) Sampling Strategy

The hybrid GA with local search strategy is integrated to deal with the deterministic pallet scheduling problem. In the second model of this study, the customers' demands will be regarded as uncertainty. According to Li's study, there are three kinds of sampling strategies in stochastic programming models, for instance, fixed samples size sampling (FSS), sample average approximation (SAA), and sequential sampling procedure (SSP) etc (Li et al. 2016). To address the non-deterministic pallet scheduling model with considering the uncertain demands, the fixed sample size (FSS) sampling strategy is used to deal with the stochastic variable in this research. The sample size *N* plays significant role on the efficiency of the HGA, namely, the larger the *N* is, the better performance of the hybrid algorithm shows. However, the large sample size may lead to the increasing of the operation time of the algorithm. Therefore, the determination of the appropriate sample size N is of great significance. In this study, different scenarios are set by the *N* value, and the FSS sampling strategy is implemented by Monte Carlo simulation.

NUMERICAL CASE

In this section, a numerical case is presented to verify the two established models on pallet scheduling and the proposed algorithm. Besides, both the deterministic programming model and the non-deterministic model considering uncertain demand are performed and compared.

Data and Parameter Setting

Parameters in the formulated models are set as the following Table 2 and Table 3 show. Firstly, we targeted the consumers' demands as precise variables, and the optimal pallet scheduling solution can be derived by the deterministic programming model.

The variables in the non-deterministic model is similar to the deterministic one illustrated in Table 2 ~ Table 3 expect the demand variable. In the non-deterministic pallet scheduling problem, the demand variable of pallet consumer is regarded as uncertain, which is described by a stochastic variable supposed to be a normally distribution. The demand variable becomes the Eq. (16).

$$D_1 \sim N(300,10); D_2 \sim N(320,8); D_3 \sim N(380,15); D_4 \sim N(260,12) \quad (20)$$

Table 2. Parameter setting in the deterministic model

Variable	Parameter setting
C_i	C_i = [2,3,1,4]; (*i*=1,2,3,4)
PC_j	PC_j =[0.8, 0.5, 1, 0.4]; (*j*=1,2,3,4)
ST_i^M	ST_i^M = [450, 500, 300, 350]; (*i*=1,2,3,4)
S_i	S_i = [450, 620, 540, 550]; (*i*=1,2,3,4)
TR_i	TR_i = [350, 400, 540, 460]; (*i*=1,2,3,4)
D_j	D_j = [300, 320, 380, 260]; (*j*=1,2,3,4)

Table 3. Transportation cost from the pallet supplier i to the customer j

Pallet supplier *i*	Pallet customer *j*			
	1	2	3	4
1	2	3	2	2
2	3	4	3	2
3	4	2	2	3
4	3	2	4	2

Results

The deterministic model and the non-deterministic model are resolved by the Matlab 2016*a* software on an Inter Core Duo E4600 CPU at 2.6GHz and 8GB RAM under Windows 10 system. To set an appropriate sample size in FSS sampling strategy in non-deterministic model, the experiment analysis is operated in different scenarios in terms of sample size N. The objective value of optimal solution and corresponding CPU time are recorded in different experimental scenarios, presented in Table 4.

From the Table 4, we can find that the best objective value shows a better performance with a larger sample size; while the CPU time soars with the increasing of the sample size. In this study, suppose the sample size N=30. The optimal solution is derived after 270 iterations achieving to a convergence in the non-deterministic pallet scheduling model, illustrated in the Figure 6. The minimized total pallet scheduling cost is about 4903.1, and the best pallet scheduling solution can be generated by the designed HGA, illustrated in the Table 5.

DISCUSSION

This study serves both theoretical contributions to modern logistics system and practical implications to the industrial plants. The novel pallet sharing alliance provides an insight to innovate the handling operations for logistics managers. Also, it extended the scope of the pallet technology in distribution center. Secondly, two pallet scheduling models under certain and uncertain scenarios are formulated to optimize the best resources allocation. It is a fundamental management technique for industrial managers to improve the pallet utilization through scientific pallet scheduling ideally. To make full use of the novel mechanism of the pallet alliance in a practical form, the non-deterministic pallet scheduling model under ambiguous pallet demands is developed as well. This model is generated under the pallet alliance environment and permits that the pallet demand is uncertain. Different with previous uncertain pallet scheduling models, this model fits the proposed pallet alliance. The proposed hybrid GA approach is implemented to derive the best pallet scheduling solution. Logistics managers or the operator in the distribution platform can make scientific arrangement on pallet scheduling through the proposed models.

Table 4. The efficiency of the HGA in terms of different sample size

Scenario 1	Sample size	Efficiency of the HGA	
		Best objective value	CPU (s)
S1	50	5403.5	4
S2	100	4903.1	9
S3	200	4756.9	21

Figure 6. Convergence iteration of the non-deterministic model

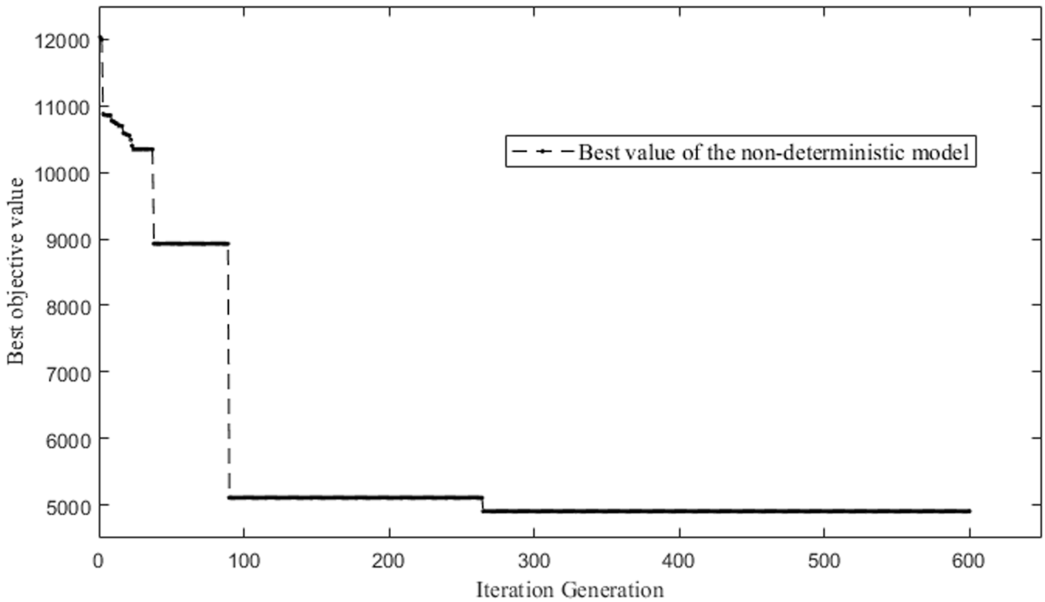


Table 5. The pallet scheduling solution in the uncertain model

Pallet supplier *i*	Pallet customer *j*			
	1	**2**	**3**	**4**
1	83	18	100	25
2	135	18	136	111
3	7	18	59	25
4	71	241	70	78

CONCLUSION

The pallet sharing mechanism has been proven to be the effective tool to improve logistics efficiency and cost reduction. The study of the pallet sharing and scheduling play a great role on modern logistics, especially in the e-commerce environment. In this study, the novel pallet sharing alliance is organized by introducing the pallet manufacturers to the pallet service system. To assist the high efficiency achievement of the pallet sharing system, two pallet scheduling programming models are formulated under deterministic and non-deterministic environment. In addition, the hybrid genetic algorithm is designed by embedding the local search strategy, and the fixed sample size sampling strategy is employed to deal with the stochastic demand variable. Finally, the numerical case shows that the formulated models could assist industrial managers to generate the optimal pallet scheduling solution both the deterministic and non-deterministic scenarios.

This study contributes to the existing pallet knowledge by developing two pallet scheduling models, however, there carriers some limitations. Firstly, other pallet sharing alliance with more stakeholders can be extended and constructed. Secondly, more uncertain factors of practical plants can be highlighted simultaneously to depict the real industrial scenario. Finally, smart heuristic algorithms with artificial intelligence could also be designed and developed to improve the search efficiency and accuracy. In the next study, we will conduct the pallet sharing alliance management practice from the abovementioned viewpoints.

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