

OPTIMIZATION DESIGN OF END-OF-LIFE VEHICLE RECYCLING SYSTEM BASED ON ExtendSim

Hongxing DENG¹, Weiqi WANG², Ying ZHAO³

Based on ExtendSim software, this paper establishes a simulation optimization model for the location, path and inventory problem of the end-of-life vehicle recycling system, a heuristic algorithm is used to solve the model based on genetic algorithm and saving algorithm. Finally, an instance is given to demonstrate the feasibility of this simulation optimization model, and then illustrates the validity of localization, path and inventory of the end-of-life vehicle recycling system simulation optimization model based on ExtendSim in solving the problem under the dynamic system condition of random recycled automobile and random vehicle transportation time.

Keywords: End-of-life vehicle recycling, ExtendSim, Simulation optimization

1. Introduction

Recently, the number of end-of-life vehicle has risen sharply, and the resulting resources, environment and social problems have become increasingly serious. In recent years, many scholars have devoted themselves to the research on the theory of recycling end-of-life vehicle. Masoud [1] developed a mathematical model which will enable vehicle manufacturers to better manage the new vehicles and ELVs transportation routes by sharing the resources. Seval Ene [2] developed a mathematical programming model for managing reverse flows in end-of-life vehicles' recovery network. This study addresses the lack of research on the design of an entire product recovery network for used vehicles. Demirel [3] and Mahmoudzadeh [4] built the mixed integer programming model and the recycling network from different perspective.

Strategic network designed for the ELVs collection problem in Mexico has been studied. Reynaldo etc. [5] regioned with high ELV generation are identified as well as relevant factors affecting total costs in the reverse supply chain. Merksiz-Guranowsk [6] presented a bi-criteria model of network entity location that takes into account the preferences of the vehicle owners and network

¹ School of Traffic and Transportation, Northeast Forestry University, Harbin 150040, China, e-mail: qiangtg123@126.com

² School of Traffic and Transportation, Northeast Forestry University, Harbin 150040, China

³ YMDD supply chain management co. LTD, Shanghai 201702, China, e-mail: 525927784@qq.com

participants. In China, the researchers focus on end-of-life vehicle recycling network model optimization and the corresponding algorithm analysis and verification etc.[7-9].

ExtendSim is simulation software developed by an American company called Imagine That Inc. Schriber [10] discussed the working principle and process of ExtendSim and other simulation software in his paper, and let users understand how the simulation software works. Krah [11] introduced ExtendSim, a program that creates, validates, and validates models to builds, allowing others to analyze the system's user interface. It does not require external interfaces, compilers, or code generators. The software's design helps simulate projects for each stage, It has been widely applied and has achieved a lot in recent years. Alireza Farnoush[12] used ExtendSim software for discrete event simulation to analyze the efficiency of the car production line. Chen Annie [13] and Kopytov Eugene [14] built simulation models by ExtendSim software to optimize the existing inventory problems. Hu [15] based on discrete event simulation theory and typical diagnostic service flow, the best configuration of system resources is obtained through the queuing strategy and the software-owned optimization module.

This paper studies the end-of-life vehicle recycling system and proposes the Location - Path - Inventory problem in the end-of-life vehicle recovery system. The ExtendSim software is used to optimize the location of the recycling center, and optimize the path between the recovery point and the recycling center or the processing center. The overall optimization of the end-of-life vehicle recycling network is promoted.

2. Analysis of end-of-life vehicle recycling system

LRIP (Location-Route-Inventory Problem) refers to the problem of location, path, and inventory. The problem of location, path optimization and inventory optimization is combined to solve the NP problem of minimum cost or maximum income. The LRIP of end-of-life vehicle recycling is a combination of the recycling center location and recycling path optimization and the end-of-life vehicle inventory problem.

When the optimal solution of the system LRIP is solved, the optimization goal is often taken as the minimization of the system cost. Based on the existing research, total cost of end-of-life vehicle recycling reverse logistics system is taken as the performance index, and the recycling center transportation time is taken as efficiency index system within the simulation period. The cost of LRIP end-of-life vehicle recycling system can be analyzed from several aspects: recycling center location and operation cost, inventory cost and the transportation cost.

2.1 The location cost of recycling center

The location cost of the recycling center refers to the construction cost of the recycling center selected from all alternative recycling centers. The construction cost is divided equally in the whole life cycle and then calculated the construction cost according to the simulation time. The construction cost in the simulation time T is defined as U_j . The sum of the operating costs of all selected recycling centers is

$$W = \sum_{j=1}^M U_j \times E_j \quad (1)$$

2.2 The operation cost of recycling center

The operation cost includes management fees, labor costs, machine depreciation costs of all recycling centers, etc. The average operation cost is converted to K on every recycling vehicle, and the recycling amount of recycling center j in one time cycle T is H_j . The sum of the total cost of all the selected recycling centers is

$$K = \sum_{j=1}^M H_j \times E_j \times k \quad (2)$$

2.3 Inventory cost

In this paper, the recycling time interval is determined according to assumption that the recycling amount obeys the Poisson distribution. In the recycling center, a simple disassembly is carried out according to the engine, the gearbox and the body. Chose the inventory strategy of (R, Q) . The inventory is checked continuously in the simulation. When a repeated manufacturing recycler reaches the delivery volume, the delivery will be done. Each time delivery volume of the engine is $DK1$, and the gearbox is $DK2$. This paper takes $DK1$ and $DK2$ as the decision variables. The inventory cost of the recycling center is calculated as follows:

The total cost of the recycling center j :

$$B_j = b0_j \times \int_0^T R0_j dt + b1_j \times \int_0^T R1_j dt + b2_j \times \int_0^T R2_j dt \quad (3)$$

The inventory cost of the recycling point:

$$A_i = \sum_{i=1}^N (a_i \times \int_0^T f_i dt) \quad (4)$$

Total inventory cost:

$$X = \sum_{j=1}^M (b0_j \times \int_0^T R0_j dt + b1_j \times \int_0^T R1_j dt + b2_j \times \int_0^T R2_j dt) \times E_j + \sum_{i=1}^N (a_i \times \int_0^T f_i dt) \quad (5)$$

Ri_j —The inventory of recycling Center j ; bi_j —Unit holding costs in recycling Center j ;

2.4 Analysis of transportation cost

The total cost of transportation is divided into the following two parts: The first part is the total cost of recycling transportation, and the second part is the total cost of recycling distribution. Since the end-of-life vehicle have a large size and weight, the transportation cost can be calculated by unit distance multiply the distance of transportation, and plus the fixed cost of the vehicle.

The total cost of transportation is:

$$Y = \sum_{j=1}^M \left\{ \sum_{q_j h_n}^{Q_j H_n} \left[\sum_{i=1}^N SS_{ji} \times F_{ji}(q_j h_n) \times d \times L_{ji} + \sum_{i=1}^N \sum_{l=1}^N S_l S_{il} \times F_{il}^1(q_j h_n) \times d \times L_{il} + G_1 \right] + \sum_{p_j S_n}^{P_j S_n} [S_j \times d_j + G_2] \right\} \times E_j \quad (6)$$

SS_{ji} : distance from the recycling center j to the collection point i ; $S_l S_{il}$: the distance between points i and i' ; $Q_j H_n$: recycling times of Recycling center j ; $q_j h_n$: the mark of number, $1 \leq q_j h_n \leq Q_j H_n$; L_{ji} : recycling vehicle load from recycling center j to recycling point i ; G_1 : total fixed fare in recycling transportation at p_{jsn} th delivery; G_2 : total fixed fare in recycling transportation at p_{jsn} th delivery;

$$F_{ji}(q_j h_n) = \begin{cases} 1 & \text{In the } q_j h_n \text{th recovery, the vehicle through the channel which} \\ & \text{recovery center } j \text{ to the recovery point } i' \\ 0 & \text{no} \end{cases}$$

$$F_{il}^1(q_j h_n) = \begin{cases} 1 & \text{In the } q_j h_n \text{th recovery, the vehicle through the channel which} \\ & \text{recovery center } i \text{ to the recovery point } i' \\ 0 & \text{no} \end{cases}$$

2.5 The total cost of system

The total cost of system is the sum of the location cost of the recycling center, the operation cost of the recycling center, the total inventory cost of the recycling center and the recycling point and the recycling center delivery in a simulation cycle T . The formula is as follows:

$$Z = W + K + X + Y \quad (7)$$

The objective function of the reverse logistics system of end-of-life vehicle recycling used in this paper is to minimize Z .

3. Construction of system simulation optimization model

The concept model consists of the simulation part and the optimization part and needs time control and event triggering mechanism to get closer to the actual simulation. The overall simulation optimization model is shown in Fig. 1. It includes Data Init for data initialization, LRIP simulation module and LRIP optimization module for end-of-life vehicle recycling. Among them, the simulation module and the optimization module are connected together by 6 lines. From the top down, the The first one is that the entity enters the optimization

module from the simulation module, triggers the nearest principle algorithm and improves the savings algorithm to generate a recovery point allocation scheme and a recovery route plan. The remaining 5 links represent the five candidate recovery center entities that completed the trigger return simulation module. The initialization module DataInt is a standard module of ExtendSim.

The end-of-life vehicle recovery LRIP simulation module and the optimization module are the highest-level modules. These two modules encapsulate ExtendSim's standard modules and low-level modules built with standard modules.

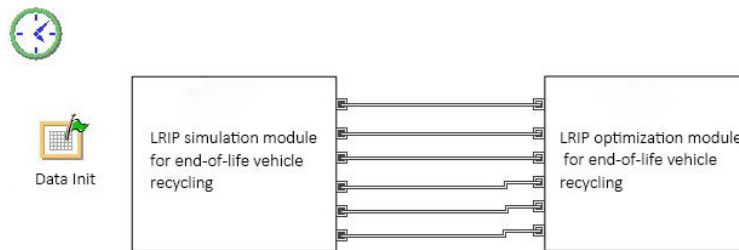


Fig. 1. The overall structure of simulation optimization model

3.1 Introduction of ExtendSim simulation software

ExtendSim adopts a modular structure, and the source code of software modules is open to users. It provides an integrated development environment with good scalability and better visibility of simulation runs and parameter modifications. Therefore, we choose it as the auxiliary software for simulation in this paper.

3.2 The construction of simulation module

Open the LRIP simulation module for end-of-life vehicle recycling. The internal structure is shown in Fig. 2. It consists of seven types of modules: Recycling Demand Generation Module, Recycling Center Departure Picking Module, Vehicle Inventory Update Module, Recycling Center Simple Disassembly Module, Recycling Center Inventory Inspection and Management Module, Recycling Center Distribution Module, and Calculation Module. The internal structure of each type of module is made up of ExtendSim's standard modules and will not be described here.

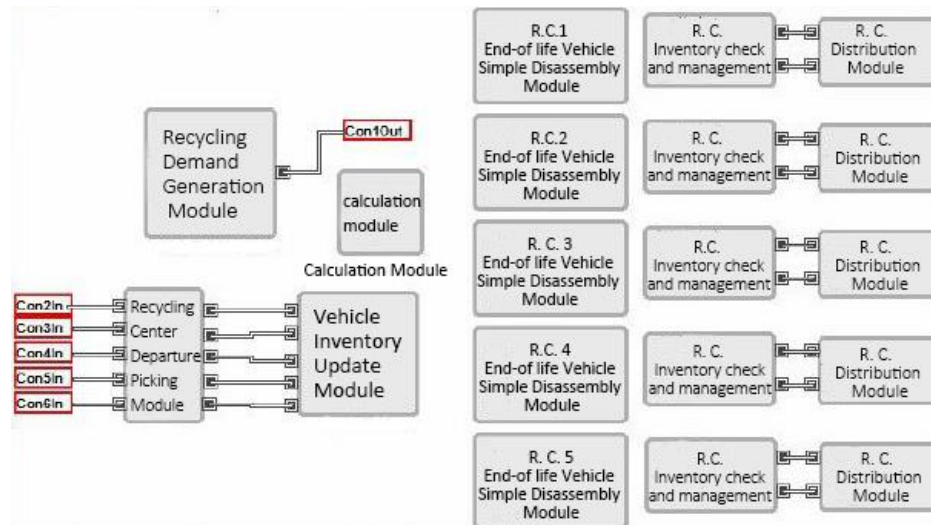


Fig. 2. the internal structure of LRIP simulation module

3.3 Construction of optimization module.

3.3.1 Optimization algorithm

The positioning—path—inventory optimization algorithm of the scrapped automobile recycling system is to calculate position (L) and stock (I) scheme with genetic algorithm by the Optimizer module in the outer module. The inner is to distribute the collecting sites to the selected recycling centers with the principle of proximity, and then solves the recycling path arrangement of the selected recycling centers using the improved saving value method. The algorithm steps are shown in Fig. 3.

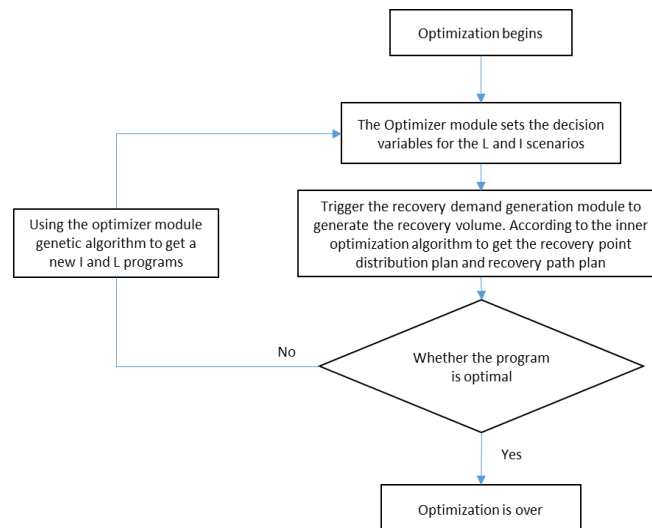


Fig. 3. Algorithm steps

3.3.2 Optimization module.

(1) Outer optimization algorithm module

The main external optimization algorithm is the Optimizer module. The Optimizer finds the optimal decision variables through the embedded genetic algorithm to get the most optimal objective. The decision variable in this paper is the location variable that represents the L scheme and the distribution point variable that represents the I scheme. The decision variables are added to the Optimizer module by four Write modules when building an external optimization algorithm module. The outer optimization algorithm module needs to set the Optimizer module. The specific steps are as follows:

A. Define the objective function equation. This paper is to minimize the operation cost, so it is defined as MinCost.

B. Drag the decision variable Clone onto the Optimizer module by the Write module.

C. Set the name and the range of variables in the Objective tab of the Optimizer module. The decision variables of L plan are C1, C2, C3, C4 and C5, which represent the location of M optional recycling centers respectively and their values range from 0 to 1. The eng_dist1, eng_dist2, eng_dist3, eng_dist4, eng_dist5 represent the decision variables of engine distribution sites of M optional recycling centers respectively. The tran_dist1, tran_dist2, tran_dist3, tran_dist4, tran_dist5 represent the decision variables of gearbox distribution sites of M optional recycling centers respectively. The value range of the engine and gearbox distribution points are set from 80% to 110% of the full load of the delivery vehicle. The total_cost is the operating cost of the system, the output variable.

D. Input the objective function "MinCost=total_cost" in the objectives tab of the Optimizer module.

E. Set the constraint equations in the Constraints tab of the Optimizer module. They constrain the M recycling centers decision variables cannot be 0 at the same time, as well as the increment in cargo capacity of the distribution vehicle. In Fig. 4, the system must select at least one of the five alternative recycling centers as the selected center. These equations are to constrain the delivery load of the engine to increase by 2, the delivery load of the gearbox increases by 6.

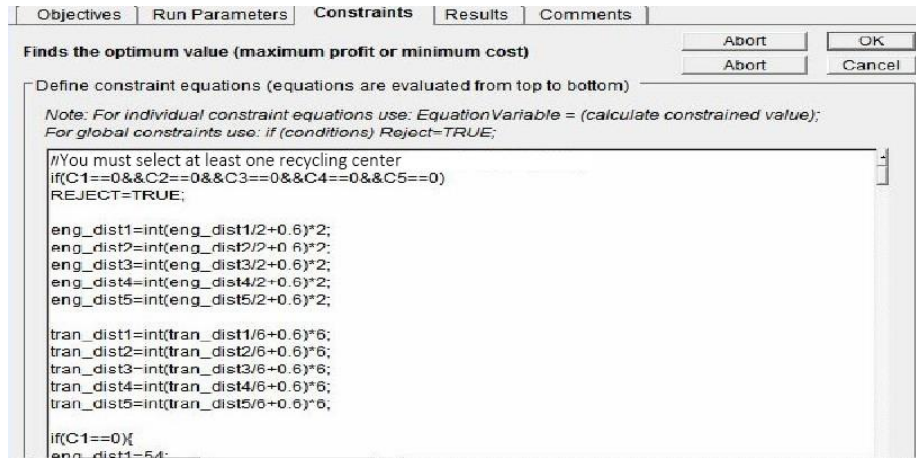


Fig. 4. Constraint equation

F. Set the optimized operating parameters in the Parameters tab of the Optimizer module. The LRIP simulation of the recycling system belongs to the stochastic model, so we should set the optimized parameters by clicking on the Quicker Defaults button of the Random model quickly. The Optimizer optimization module is set up.

(2) *Internal optimization algorithm module.*

The function of the inner optimization algorithm module is to allocate the collecting sites to the selected recycling center, and the best recycling routes of each recycling center is calculated. Its internal structure consists of Equation (I), Unbatch, Information, NCWEquation (I) and Exit.

The construction of inner optimization algorithm module comes from the entity of recycling demand module. The Equation (I) module reads the L plan codes and the principle of proximity algorithm codes. The entity travels from the Equation (I) module to the Unbatch module. It is divided into M routes to reach M Select Item Out modules. The Select the Item Out module choose the routes for the entity according to the L plan which is transferred by the Equation (I) module. The entity exits from the top port of the Exit module if the recycling center is not selected, and it travels from Information module to NCWEquation (I) module if the recycling center is selected. The NCWEquation (I) module is the internal structure of the Equation (I) module that incorporates the improved savings algorithm codes. The logical flow chart of the improved saving algorithm is shown in Fig. 5. The main codes are written in the MODL language of ExtendSim.

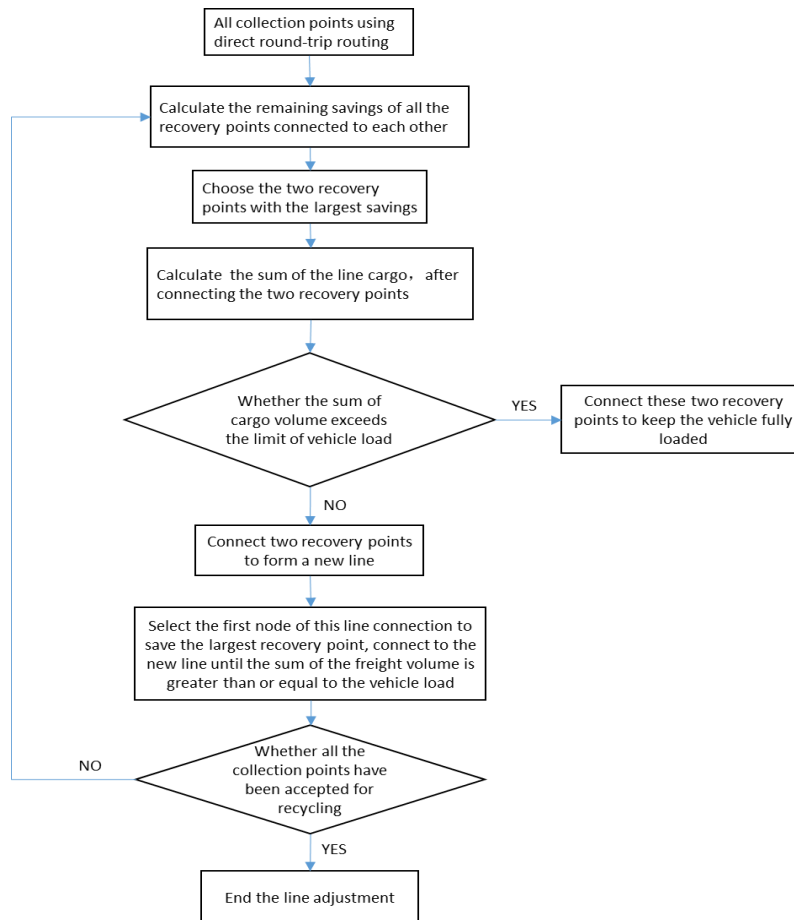


Fig. 5. Logic flowcharts to improve savings algorithm

4. Example analysis

4.1 Basic data input

The default time unit of the simulation system is day, and the total time of each simulation is 30 days. The simulation optimization goal is to minimize the total cost of 30 days. The basic data of the simulation optimization system includes the definitive data inputting and the stochastic data inputting.

4.2 Optimization setting

Before simulation optimization, the Optimizer needs to be set up. It includes decision variables, objective functions, constraint conditions, and operating parameters setting.

4.2.1 The decision variables and objective function setting

The objective function is $\text{MinCost} = \text{total_cost}$. The decision variables mainly include the recovery center location plan, the delivery vehicle carrying

capacity of the engine and gearbox. The variables of location plan are C1, C2, C3, C4 and C5, and the values are (0, 1). The “eng_dist” represents the decision variables of engine distribution site, which can satisfy the 80% requirement of the full capacity of the delivery vehicle. The values are (44, 60). The “tran_dist” represents the decision variables of gearbox distribution site and the values are (102, 140).

4.2.2 The constraint conditions and optimized operating parameters setting

(1) Setting of constraint conditions. In the simulation optimization, the value of variables is limited with constraint conditions to make them more realistic. The setting of constraint conditions is shown in Fig. 6.

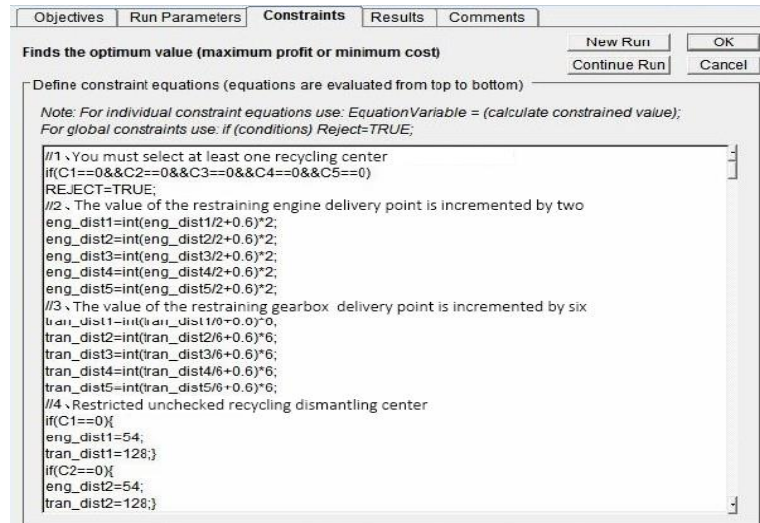


Fig. 6. Constraint setting

(2) Optimized operation parameters setting. The optimization parameters are set quickly by clicking the Quick Defaults button of the Random model. The setting is shown in Fig. 7.

Fig. 7. Parameter setting

4.3 Analysis of the example results

The ordinary flat trucks and car transport vehicles are commonly used for car carrying. This paper chooses the two types vehicles as the recycling vehicles to simulate many times. The simulation optimization results are shown in Fig. 8 and Fig. 9.

	C1	C2	C3	C4	C5	eng_dist1	eng_d	eng_d	eng_d	eng_d	total	tran_d	tran	tran	tran	tran	Mini
best	0	0	0	1	1	0	54	54	54	54	54	128	128	128	128	128	90235
1	0	0	0	1	1	0	54	54	54	54	54	128	128	128	128	128	91043
2	0	0	0	1	1	0	54	54	54	54	54	128	128	128	128	128	95127
3	0	0	0	1	1	0	54	54	54	54	54	128	128	128	128	128	97123
4	0	0	0	1	1	0	54	54	54	54	54	128	128	128	128	128	97831
5	0	0	0	1	1	0	54	54	54	54	54	128	128	128	128	128	98324
6	0	0	0	1	1	0	54	54	54	54	54	128	128	128	128	128	98743
7	0	0	0	1	1	0	54	54	54	54	54	128	128	128	128	128	99123
8	0	0	0	1	1	0	54	54	54	54	54	128	128	128	128	128	99560
9	0	0	0	1	1	0	54	54	54	54	54	128	128	128	128	128	10203
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Current convergence metrics: mean
Value 896805.702728 Convergence 95.1237%
Mean 1157993.03879 Sample 0
Elapsed time 03:23:33
Total cases 463
Total samples 2379

Fig. 8. the optimization result of taking passenger cars as transportation vehicle.

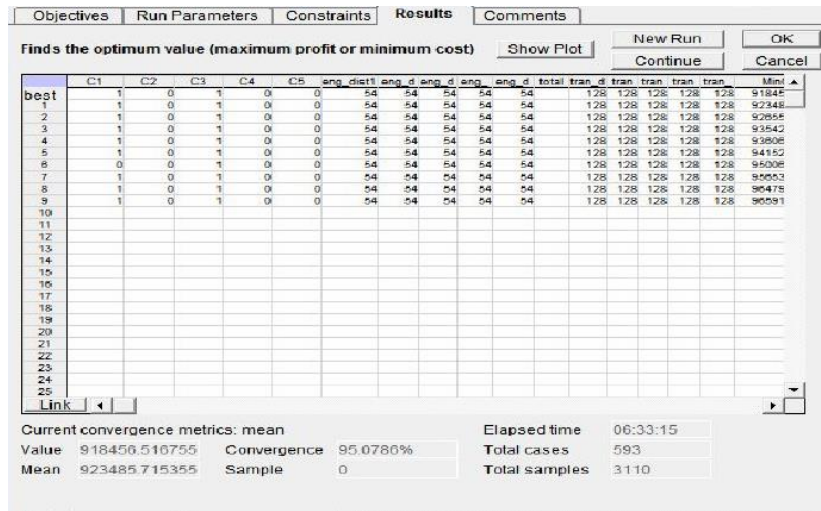


Fig. 9. The optimization result of taking Ordinary flat plate carrier as transportation vehicle.

In order to make the optimization results are more consistent, we need to run the optimization model many times. In this paper, a total of 6 simulations were carried out for the recycling vehicles of 14 vehicles and 23 vehicles respectively. The optimization results are summarized into the summary table of the 6 plans, which is shown in Table 1.

Table 1

Prioritization scheme						
o.	Facility location results	cargo capacity of recovery vehicle /vehicle	Engine distribution point/vehicle	Distribution point of gearbox /vehicle	system operation cost (RMB)	
	C3=C4=1	23	eng_dist3=54	tran_dist3=128	902357.4679	
	C1=C2=C5=0		eng_dist4=54	tran_dist4=128		
	C1=C3=1		eng_dist1=54	tran_dist1=114		
	C2=C4=C5=0	23	eng_dist3=54	tran_dist3=126	911745.342	
	C1=C3=1		eng_dist1=54	tran_dist1=114		
	C2=C4=C5=0		eng_dist3=52	tran_dist3=120		
	C1=C3=1	14	eng_dist1=54	tran_dist1=128	890336.4689	
	C2=C4=C5=0		eng_dist3=54	tran_dist3=128		
	C1=C5=1		eng_dist1=48	tran_dist1=108		
	C2=C3=C4=0	14	eng_dist5=54	tran_dist5=108	966434.7257	
	C4=1					
	C1=C2=C3=C5=0		eng_dist4=48	tran_dist4=128		

The optimization results are shown in table 2. Compared with the system performance parameters, the best solutions are choosed with the scrapped automobiles recycling enterprise standards eventually. The simulation parameters, distribution centers of engine and gearbox are set according to the optimized plan.

The number of simulation is 10. The simulation results are summarized are calculated with Mean&Variance modules

Table 2

Simulation result							
o.	total system cost /RMB	Recovery point inventory cost/RMB	Vehicle inventory cost/RMB	Transmission inventory cost/RMB	Engine inventory cost/RMB	transportation cost /RMB	transport time / (h)
	1210166.8	7647.65	5059.41	18560.95	8322.68	613090.06	465.28
	1174388.8	9092.95	4498.97	19249.12	7904.2	525679.59	496.69
	1188437.7	8918.89	4718.02	17134.39	8614.11	533766.29	507.99
	1261026.4	9269.35	4948.27	19811.55	8008.9	585173.3	544.71
	1321629.9	9922.31	5570.66	17971.48	7260.49	606593.93	569.97
	1353184.9	13933.72	22440.48	8689.84	3440.1	768582.1	1014.591

The system optimization goal--the lowest total cost, the recycling efficiency and the inventory cost of each facility point were considered in choosing the optimal plan. Comprehensive analysis of the above 6 plans, plan 3 is the best. Considering that the car carrier is restricted to over-limit transport, the best plans are plan 3 and plan 4.

5. Conclusion

Based on the theories of end-of-life vehicle recycling and simulation, this paper studies the dynamic recycling logistics system of LRIP (location-path - inventory) problem. Adopting the principle of nested nearest to solve the distribution problem and improved algorithm for solving vehicle routing. The outer layer is solved by a hybrid genetic algorithm solution, including a repossession center location plan and an inventory control plan. Using the ExtendSim simulation software, the mathematical model and conceptual model of LRIP of the scrapped automobile recycling logistics system are established. Compared to the 6 simulation results, the total cost of the car carrier plan is significantly lower than others. Considering the transportation time and overloading transportation, plan 3 and plan 4 are the best plans.

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