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Abstract

Purpose – The purpose of this paper is to formulate and simulate the model for vehicle routing problem (VRP) on a practical application in logistics distribution.

Design/methodology/approach – Based on the real data of a distribution center in Utica, Michigan, USA, the design of VRP is modeled as a multi-objective optimization problem which considers three objectives. The non-dominated sorting genetic algorithm II (NSGA-II) is adopted to solve this multi-objective problem. On the other hand, the VRP model is simulated and an object-oriented idea is employed to analyze the classes, functions, and attributes of all involved objects on VRP. A modularized objectification model is established on AnyLogic software, which can simulate the practical distribution process by changing parameters dynamically and randomly. The simulation model automatically controls vehicles motion by programs, and has strong expansibility. Meanwhile, the model credibility is strengthened by introducing random traffic flow to simulate practical traffic conditions.

Findings – The computational results show that the NSGA-II algorithm is effective in solving this practical problem. Moreover, the simulation results suggest that by analyzing and controlling specific key factors of VRP, the distribution center can get useful information for vehicle scheduling and routing.

Originality/value – Multi-objective problems are seldom considered on VRPs, yet they are of great practical value in logistics distribution. This paper is mainly focused on multi-objective VRP which is derived from a practical distribution center. The NSGA-II algorithm is applied in this problem and the AnyLogic software is employed as the simulation tool. In addition, this paper deals with several key factors of VRP in order to control and simulate the distribution process. The computational and simulation results regarding VRPs constitute the main contribution of our paper.

Keywords Simulation, Distribution management, Modelling, Computer software

Paper type Research paper

1. Introduction

Throughout the world, physical distribution has been developing rapidly during recent decades, while demands for customers have been increasing. A number of distribution centers have emerged and expanded under these circumstances. Fast delivery makes a logistics company more competitive, and the distribution cost is an essential problem it concerns. Therefore, vehicle routing is a problem of undeniable practical significance in logistics distribution.

The vehicle routing problem (VRP) was first proposed by Dantzig and Ramser (1959). It is an extension of the travelling salesman problem. During the past five decades, the VRP models have been developing rapidly and many other new models have derived from this original model (Jing, 2004; Kim and Zeigler, 1991; Vieira, 2004; Shabayek and Yeung, 2002; Liu *et al.*, 2004).

This paper is based on the vehicle routing problem with time windows (VRPTW), where a set of vehicles with limited truckload are to be routed from a distribution center

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to a set of geographically dispersed customers with known demands and predefined time windows. Once, a vehicle arrives at a customer earlier than its earliest service time or later than the latest service time, a penalty must be paid for unpunctuality (penalties may differ from one to another). Some recent publications of VRPTW can be found (Braysy, 2003; Chavalitwongse *et al.*, 2003; Gezdur and Türkay, 2002; Li and Lim, 2003; Breedam, 2001; Ibaraki *et al.*, 2005; Bodin, 1990; Tan *et al.*, 2006; Lin and Kwok, 2006).

VRP is not only a theoretical conundrum in Operations Research, but also a useful practical problem. It is not enough to get the distribution routes only by theoretical algorithms with certain conditions. In recent years, computer simulation is widely used on studies in logistics distribution. The simulation technology supplies the research of complicated distribution system with direct and effective analysis methods.

Simulations are model-based activities which require computer recognizable and runnable simulation models. The theories and methods of modeling are the basis of simulation and also important factors for simulation technology development. The formal modeling is a method to describe and analyze systems by states equations. Using massive mathematical tools, the formal modeling includes queueing network (QN), maximum algebra (MA), perturbation analysis (PA), Petri net, etc.

Solberg (1977) initially applied QN in dynamic system modeling for discrete event. MA was given by Cohen *et al.* (1985) handling flexible production line. PA was first developed by Ho and Cassandras (1983) from Harvard University. Petri net model was first initiated by Carl Adam Petri in his doctoral dissertation in 1962. Then, Sawhney *et al.* (1999) used Petri net in mails handling center by analyzing and optimizing the work flow of the whole processing center.

The remainder of this paper is organized as follows: Section 2 states a practical application we are dealing with and then formulates a mathematical model for the multi-objective problem. Section 3 describes the simulation modeling process, while Section 4 further illustrates the non-dominated sorting genetic algorithm II (NSGA-II) algorithm on solving the multi-objective model. Computational results and analysis are presented in Section 5. Finally, the summary and conclusions of this paper are presented in Section 6.

2. Problem statement and mathematical modeling

The main motivation of solving a multi-objective VRP came from a practical application of a distribution center in Michigan, USA, where thousands of goods are being delivered to hundreds of cities all over the country. We model this problem as follows.

Based on the single-objective optimization model by Golden and Wasil (1987), we propose a multi-objective VRP model, combined with capacitated vehicle routing problem and VRPTW model.

The distribution center transports goods to customers with multiple vehicles. The locations and demands of customers are given and the capacity of vehicles is fixed. In addition, all demands must be satisfied and each customer must be serviced at a certain time. The aim is to choose the optimal or near optimal routes, where three objectives need to be considered to:

(1) minimize the total distance of all the vehicles;

(2) minimize the total number of vehicles; and

(3) service the customers as punctually as possible.

The constraints are:

- the vehicle capacities must not be violated;
- the demand of each customer must be satisfied, and must be serviced by exactly one vehicle; and
- each vehicle starts from the distribution center and returns to it when finishing its distribution.

Suppose there are altogether C customers (we represent them as $1, 2, \ldots, C$; specifically 0 corresponds to the distribution center). Each customer has a demand w_i and requires an arrival time T_i ($i = 1, 2, \ldots, C$). The distance between i and j is d_{ij} ($i, j = 0, 1, \ldots, C$; $d_{ii} = 0$). Since the demand of each customer is no more than the vehicle capacity W, the vehicle number K is no more than the customer number C, that is, $K \leq C$. Let n_k be the number of customers distributed by the kth vehicle ($n_k = 0$ means that vehicle k is disengaged). The set R_k contains the customers on the distribution route of vehicle k, and $r_i^k \in R_k$ represents the ith customer of route k ($r_0^k = 0$ be the distribution center). The average velocity of vehicles is set to be v.

A multi-objective model is formulated as follows:

$$\min Z_1 = \sum_{k=1}^{K} \left(\sum_{i=1}^{n_k} d_{r_{i-1}^k r_i^k} + d_{r_{nk}^k 0} \right) \tag{1}$$

$$\min Z_2 = K \tag{2}$$

$$\min Z_3 = \sum_{k=1}^{K} \sum_{i=1}^{n_k} \begin{cases} \left| T_i - \sum_{j=1}^{i} t_{r_{j-1}^k r_j^k} \right| P_1, & T_i - \sum_{j=1}^{i} t_{r_{j-1}^k r_j^k} \geq 0 \\ \left| T_i - \sum_{j=1}^{i} t_{r_{j-1}^k r_j^k} \right| P_2, & T_i - \sum_{j=1}^{i} t_{r_{j-1}^k r_j^k} < 0 \end{cases} \tag{3}$$

subject to:

$$\sum_{i=1}^{n_k} w_{r_{ki}} \leq W_k, \quad k = 1, \ldots, K \tag{4}$$

$$\sum_{k=1}^{K} n_k = C, \quad 0 \leq n_k \leq C \tag{5}$$

$$R_i \cap R_j = \varnothing, \quad 1 \leq i \neq j \leq K \tag{6}$$

$$t_{ij} = \frac{d_{ij}}{v}, \quad 1 \leq i \neq j \leq C \tag{7}$$

Objective (1) minimizes the total distance of all vehicles.

Objective (2) minimizes the total number of vehicles.

Objective (3) minimizes the total penalty of unpunctuality for all vehicles, where P_1 and P_2 represent the penalty rates for being early and late separately.

Constraint (4) demonstrates that vehicle capacities cannot be violated.

Constraint (5) ensures that all customer demands must be delivered.

Constraint (6) represents that no two vehicles visit the same customer, i.e. each customer is visited exactly once.

Constraint (7) calculates the travel time between i and j.

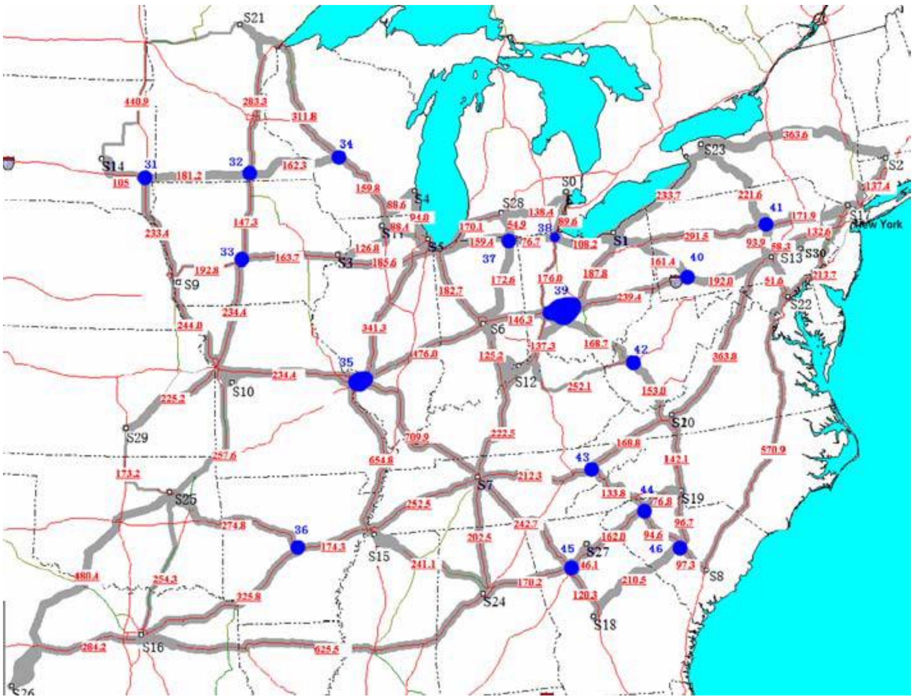
3. Simulation modeling

To make it clear for simulation, we consider only 30 customers among hundreds of customers for the distribution center.

3.1 Data preparation

The distribution center is located at Utica, Michigan, USA. We select 30 cities in North America for the distribution points as customers. Apart from the 30 distribution points, there are 16 road junctions. We label these junctions for route expression: number 1-30 present distribution points separately, while the number 31-46 are junctions. Therefore, we can represent the routes by two-digit numbers and "-". With PCMiler software we obtain the distances shown in Figure 1.

Moreover, the fact should be taken into consideration that in most cases the routes are linked by distribution points which presented by 1-30. However, a junction may exist between two customers. For instance, a route may be expressed as "01-28," yet the actual route is "01-38-37-28." In this case, we need the real distances between every two distribution points.



Note: Distance included

Figure 1.
Distribution network

Before establishing the simulation model, first we should determine the simulation goal based on the VRP to be modeled, and then analyze according to the simulation goal. To establish a hierarchical, objectificated and modularized model, we adopt an object-oriented analysis method to determine the functions and attributions of each object. After analysis, data statistics are necessary, including determination of the locations of the distribution center and each distribution point, the distance calculation and the actual distances between every two distribution points. Finally, a brief introduction and direction is given for using the AnyLogic simulation software.

3.2 Logic flow

The logic flow of VRP can be summarized in three steps:

(1) construction of the whole communication networks;
(2) distribution process; and
(3) the simulation results.

(1) Construction of the whole communication networks. As mentioned above, this is to evaluate and initialize each necessary attribution of the analyzed objects, including the initialization of customer points (serial number, serial number of adjacent distribution points, and evaluation of standing time), initialization of roads (length evaluation and velocity evaluation), initialization of distribution vehicles (serial number, distribution route, and the whole route).

Based on the features of AnyLogic, we adopt a modularized and objectificated modeling method. Figure 2 shows a tree structure of the whole model, which can be separated into four parts according to the difference of functions:

(1) message class;
(2) object class;
(3) animation; and
(4) dataset.

(2) Distribution process. This part is implemented by computer programs, which we have written to control the actions of all vehicles.

(3) The simulation results. It is not only to obtain an animation effect to simulate the distribution process, but also more importantly to get the ultimate simulation results. According to the objective functions, we conclude that the results are focused on three aspects:

(1) total travel distance;
(2) distribution time; and
(3) vehicle number.

4. NSGA-II algorithm

We have formulated both mathematical and simulation models. The main approach in solving the models is NSGA-II, which is quite efficient for multi-objective problems. NSGA-II is a revised version of NSGA (Wei, 2007), based on the classic genetic algorithm (GA).

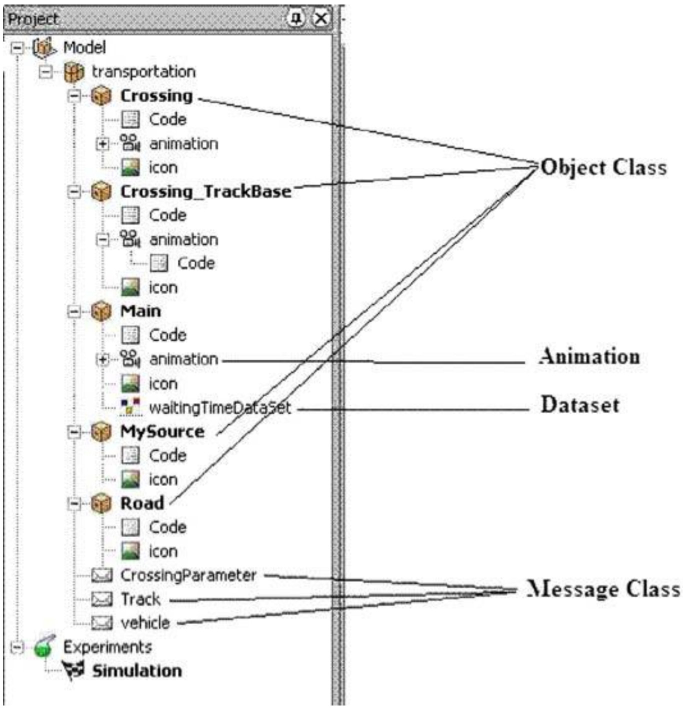


Figure 2.
Tree structure
of the whole model

The fundamental difference between NSGA-II and GA is that, a non-dominated sorting and crowding-distance sorting process is proposed aiming at the multi-objective problem. The main procedure of NSGA-II (Wei *et al.*, 2008) is shown as Figure 3.

The selection, crossover, and mutation operators are the same as classic GAs, and here we discuss only some details of non-dominated sorting process.

(1) Non-dominated sorting

Sort the population by non-domination into each front, so that the:

- first front is completely non-dominant by any other individuals;
- second front is dominated only by the individuals in the first front; and
- front goes so on.

Fitness value is assigned to each front by 1 for the first front, 2 for the second, and so forth.

(2) Crowding distance sorting

Assign crowding distance to each individual in each front. It is measured by how close an individual is to its neighbors. The main idea behind crowding distance is finding the Euclidian distance between each individual in a front based on their m-objectives in the m-dimensional hyper space. The individuals in the boundary are always selected since they have infinite distance assignment.

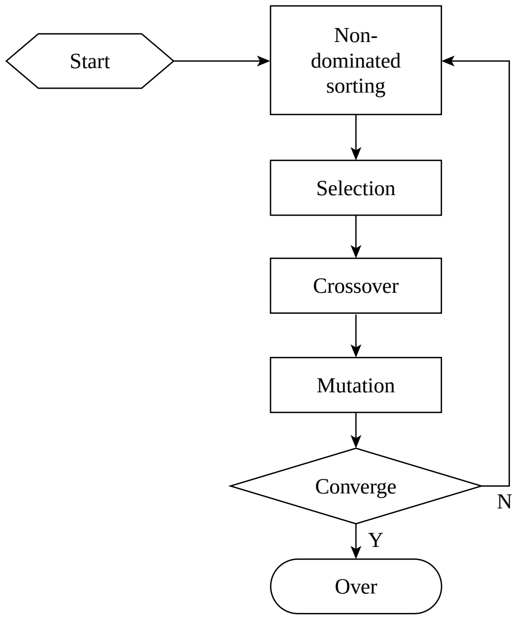


Figure 3.
NSGA-II procedure

5. Results analysis

5.1 Simulation tests

As is mentioned in Section 3.1, we obtain the distribution orders of 30 customers, including demands and arriving times. Besides, through the optimization algorithm in Section 4, we get a group of distribution results (Table I): RealRoute and WholeRoute (arrangement of RealRoute).

Table I.
Distribution results

TrackID	RealRoute	WholeRoute
1	00-25-26-00	00-28-05-35-25-26-16-36-15-35-05-28-00
2	00-05-11-03-00	00-28-05-11-03-05-28-00
3	00-10-29-16-00	00-28-05-35-10-29-25-16-36-15-35-05-28-00
4	00-17-30-01-23-00	00-38-01-41-17-30-13-41-01-23-00
5	00-07-15-12-00	00-38-39-12-07-15-07-12-39-38-00
6	00-13-22-02-00	00-38-01-41-13-22-17-02-23-00
7	00-06-00	00-28-37-06-37-28-00
8	00-27-19-00	00-38-39-12-43-27-44-19-20-42-40-01-38-00
9	00-09-14-21-00	00-28-05-03-33-09-31-14-21-34-11-05-28-00
10	00-08-18-24-00	00-38-01-39-42-20-19-46-08-46-18-45-24-07-12-39-38-00
11	00-28-00	00-28-00
12	00-20-04-00	00-38-01-39-42-20-42-39-06-05-04-05-28-00

5.2 Running

After model initialization, click "run" and the model starts to simulate. The simulation interface is shown in Figure 4. In this distribution network, the moving little green squares show the normal traffic flow, while the bigger red squares represent the distribution vehicles.

Meanwhile, to enhance the flexibility of the model, we introduce the online modification and implementation functions of input/output data. In Figure 4, the standing time is set to 0.5 (about 30 min) and the travel speed is set to 30. The pillar above shows the average crowding level of crossings. And the current crowding level is 8.982 (about 10 min).

5.3 Results analysis

When all the red distribution vehicles return to the distribution center, the whole distribution process terminates. Click "stop" and we obtain the records of this simulation process, part of which is shown in Figure 5. The result contains the arrival time of each vehicle to its distribution points, and the whole distribution route.

According to the constraints to the objectives before, we may evaluate this method from three aspects:

(1) vehicle number;

(2) total travel distance; and

(3) punctual level of arrivals.

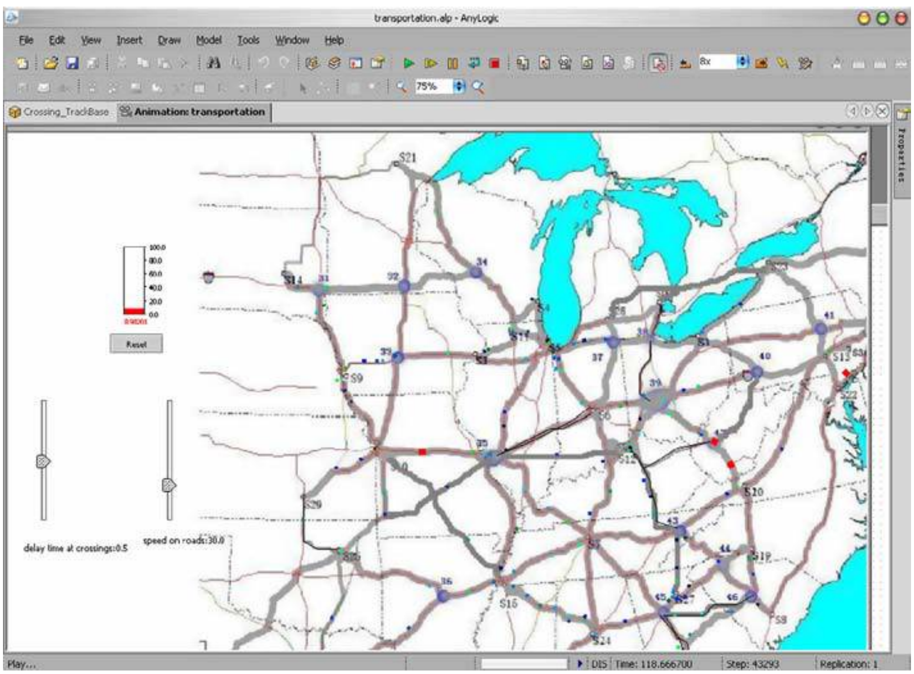


Figure 4.
Simulation interface

```
Started...
AnyLogic simulation engine has started [$Id: Engine.java,v 1.134 2004/12/03 08:49:39 basil Exp $]

Crowding Level = 30
delayTime = 0.5

Start time: 500.0

Time: 549.00, Vehicle: 01 arrived at 25, remaining route: 26-00
Time: 561.50, Vehicle: 01 arrived at 26, remaining route: 00

Time: 524.00, Vehicle: 02 arrived at 05, remaining route: 11-03-00
Time: 537.50, Vehicle: 02 arrived at 11, remaining route: 03-00
Time: 548.00, Vehicle: 02 arrived at 03, remaining route: 00

Time: 550.50, Vehicle: 03 arrived at 10, remaining route: 29-16-00
Time: 884.50, Vehicle: 03 arrived at 29, remaining route: 16-00
Time: 927.00, Vehicle: 03 arrived at 16, remaining route: 00

Time: 543.00, Vehicle: 04 arrived at 17, remaining route: 30-01-23-00
Time: 554.00, Vehicle: 04 arrived at 30, remaining route: 01-23-00
Time: 599.50, Vehicle: 04 arrived at 01, remaining route: 23-00
Time: 610.00, Vehicle: 04 arrived at 23, remaining route: 00

Time: 766.50, Vehicle: 05 arrived at 07, remaining route: 15-12-00
Time: 777.00, Vehicle: 05 arrived at 15, remaining route: 12-00
Time: 798.50, Vehicle: 05 arrived at 12, remaining route: 00

Time: 545.00, Vehicle: 06 arrived at 13, remaining route: 22-02-00
Time: 565.00, Vehicle: 06 arrived at 22, remaining route: 02-00
Time: 589.00, Vehicle: 06 arrived at 02, remaining route: 00

Time: 537.50, Vehicle: 07 arrived at 06, remaining route: 00

Time: 777.50, Vehicle: 08 arrived at 27, remaining route: 19-00
Time: 798.50, Vehicle: 08 arrived at 19, remaining route: 00

Time: 559.50, Vehicle: 09 arrived at 09, remaining route: 14-21-00
Time: 580.50, Vehicle: 09 arrived at 14, remaining route: 21-00
Time: 591.00, Vehicle: 09 arrived at 21, remaining route: 00

Time: 586.50, Vehicle: 10 arrived at 08, remaining route: 18-24-00
Time: 607.50, Vehicle: 10 arrived at 18, remaining route: 24-00
Time: 629.00, Vehicle: 10 arrived at 24, remaining route: 00

Time: 515.50, Vehicle: 11 arrived at 28, remaining route: 00

Time: 558.00, Vehicle: 12 arrived at 20, remaining route: 04-00
Time: 621.00, Vehicle: 12 arrived at 04, remaining route: 00

Distribution completed.
```

Note: Part

Figure 5.
Records of the simulation process

(1) The effects of crowding level on arrival punctuality. In general, VRP algorithms, the crowding level of roads is not taken into account. However, in fact, especially for the current traffic situation in China, the crowding level of crossings will have a remarkable influence on logistics distribution. Some distribution strategies can run well in smooth flow of traffic, yet may not be able to finish all orders under traffic jams. Hence, we add a new resource to simulate normal vehicle flows, so that we can analyze the influence on the vehicle distribution by the crowding level.

Here, we introduce a method to quantitatively evaluate the arrival punctuality of vehicles. According to mathematical model, a punctual arrival time is required, earlier or later is unwished. Therefore, we first calculate the difference (or the absolute difference) between the actual arrival time and the required arrival time for each customer, and then sum up the differences. Table II shows a statistics table of punctuality level of vehicles, including the required arrival time T_0 at each point and the simulated arrival time T.

The variable definitions are:

$$Time\ \ difference = T_0 - 20 \times (T - t_0) \tag{8}$$

where t_0 is the start time of distributive simulation; and

$$Absolute\ \ time\ \ difference = |Time\ \ difference| \tag{9}$$

From Figure 6, we can see that *Time difference* might be negative, meaning the arrival time is later than requirement. If we simply sum them up, there may be some

		Crowding level 60			Crowding level 50
No.	T_0	T	Time difference	Absolute time difference	
0	0	500	0	0	500
1	1,920	593.8001833	43.99633333	43.99633333	594.7508667
2	1,850	577.2001167	305.9976667	305.9976667	575.2501167
3	3,140	547.2001333	2,195.997333	2,195.997333	549.5000833
4	300	613.20005	−1,964.001	1,964.001	618.2500667
5	4,320	522.6000333	3,867.999333	3,867.999333	527.5000333
6	700	536.2003833	−24.00766667	24.00766667	539.25005
7	830	1,107.600017	−11,322.00033	11,322.00033	1,052.500017
8	860	590.4001333	−948.0026667	948.0026667	591.2501167
9	720	564.4001333	−576.0006667	576.0006667	557.7500333
10	750	545.0001167	−150.0023333	150.0023333	548.2501
11	2,570	535.8001	1,853.998	1,853.998	538.7500667
12	2,110	1,140.000067	−10,690.00133	10,690.00133	1,087.500333
13	2,150	544.8000667	1,253.998667	1,253.998667	543.0000667
14	2,970	606.0003	849.994	849.994	587.2501
15	2,900	1,118.400033	−9,468.000667	9,468.000667	1,064.000333
16	2,540	1,193.20005	−11,324.001	11,324.001	1,160.750033
17	1,710	550.6001167	697.9976667	697.9976667	551.7508
18	4,570	612.0001667	2,329.996667	2,329.996667	612.75015
19	4,420	1,142.400067	−8,428.001333	8,428.001333	1,086.500067
20	2,010	556.6000833	877.9983333	877.9983333	562.7500667
21	2,670	619.40035	281.993	281.993	599.7501167
22	2,530	555.6000833	1,417.998333	1,417.998333	553.7500833
23	1,020	605.4002167	−1,088.004333	1,088.004333	605.5008833
24	1,540	633.6002	−1,132.004	1,132.004	634.5001
25	1,450	553.0001167	389.9976667	389.9976667	550.5001
26	2,270	579.200015	685.997	685.997	609.2501833
27	1,780	1,120.800033	−10,636.00067	10,636.00067	1,064.00033

Note: Part

Table II. Statistics table of punctuality level

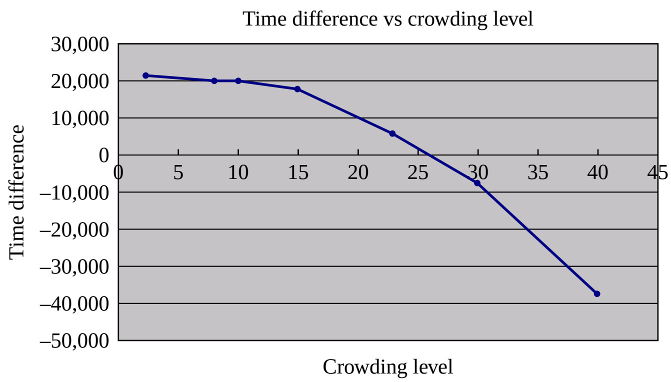


Figure 6.
Time difference curve

neutralization between positive and negative differences. Hence, we should sum up *Absolute time differences*.

The average waiting time (WaitingTimeDataSet.mean()) is defined to reflect the crowding level at crossings. Therefore, by adjusting DelayTime in crossing class, we can change the crowding level. For example, let DelayTime = 0.5, then the crowding level is 30. This demonstrates that it takes 30 min to load or unload goods at each point. The crowding level is only a weighing term, thus more symbolical than real.

Repeat tests like this: first change DelayTime, next wait until the crowding level is stable, and then send out the distribution vehicles. Finally, after distribution, evaluate the arrival punctuality (Table III).

As the crowding level increases, the absolute time difference grows rapidly, implying that the unpunctuality is becoming more and more serious. Besides, we can also tell from Figures 6 and 7 that before the crowding level reaches 15, the variation range of the absolute time difference is very small. However, after 15, the variation range grows faster and faster. If we assume that the distribution plan is inadaptable when the absolute time difference is beyond 5,000, then we can make a conclusion: if by pre-statistics, the crowding level is below 15, the distribution plan is acceptable; or else, if it is beyond 15, the plan is inadaptable and needs improvement.

(2) The effects of time window on arrival punctuality. Time window is a basic requirement of customers to the distribution center, and is a key factor of improving

Table III.
Crowding level and time difference

Crowding level	Time difference	Absolute time difference
2.5	21,420.937	36,857.97
8	19,697.937	36,790.98
10	19,893.925	37,025.97
15	17,261.886	38,317.97
23	5,337.894	43,533.99
30	− 8,120.101	56,539.99
40	− 37,698.073	84,153.99

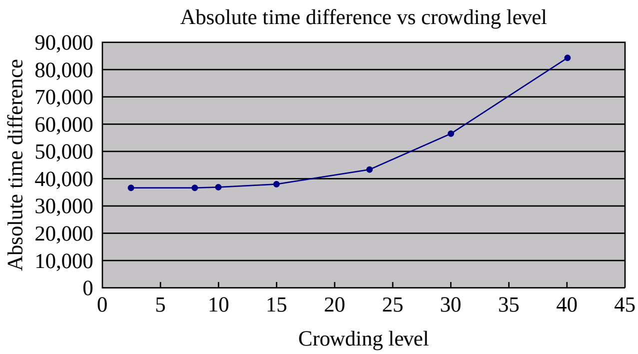


Figure 7.
Absolute time difference curve

the service quality of the distributive center. In general cases, customers would require a narrow time window, therefore we consider only an exact point of arrival time and being early or late will be punished. But in practice, due to the complex changes of urban traffic conditions, it is hard or even impossible to fit the very narrow time window. As a result, it is over ideal to evaluate arrival punctuality. Therefore, based on the conditions in the last section, we discuss the distribution results under different widths of time window.

Assume that the required arrival time of customer i is T_i, and the simulated arrival time is $\hat{T}_i$. Then, the *Time Window* can be defined as $[ET_i, LT_i]$, where $ET_i = T_i \times (1-\alpha)$, and $LT_i = T_i \times (1+\alpha)$, $(0 \leq \alpha \leq 1)$. Hence, the arrival punctuality of customer i can be defined as:

$$OT_i = \begin{cases} ET_i - AT_i & AT_i < ET_i \\ 0 & ET_i \leq AT_i \leq LT_i \\ AT_i - LT_i & AT_i > LT_i \end{cases} \tag{10}$$

The punctuality of the whole distribution process is defined as:

$$OTS = \frac{1}{n}\sum_{i=1}^{n} OT_i \tag{11}$$

Apparently, the smaller is OTS, the better is the punctuality of the whole distribution system.

Table IV indicates a statistics of the width of time window and the arrival punctuality of vehicles. After summing up the data, we get Table V and Figure 8.

It can be summarized that as the width of time window increases, the arrival punctuality grows better. Take 5,000 for the evaluation criterion, and requirement can be satisfied if the time window proportion parameter α is larger than 10 percent. However, we should also notice that it will be meaningless when the time window is

Table IV.
Time window – punctuality contrast

20%			30%			40%			50%		
Left	Right	Punctuality	Left	Right	Punctuality	Left	Right	Punctuality	Left	Right	Puntuality
1,536	2,304	0	1,344	2,496	0	1,152	2,688	0	960	2,880	0
1,480	2,220	0	1,295	2,405	0	1,110	2,590	0	925	2,775	0
2,512	3,768	1,551.997	2,198	4,082	1,237.997	1,884	4,396	923.997	1,570	4,710	609.99
240	360	2,060.008334	210	390	2,030.00833	180	420	2,000.008334	150	450	1,970.008
3,456	5,184	2,975.999334	3,024	5,616	2,543.99933	2,592	6,048	2,111.999334	2,160	6,480	1,679.999
560	840	0	490	910	0	420	980	0	350	1,050	0
664	996	4,334.000334	581	1,079	4,251.00033	498	1,162	4,168.000334	415	1,245	4,085.000
688	1,032	698.002666	602	1,118	612.002666	516	1,204	526.002666	430	1,290	440.002
576	864	326.001666	504	936	254.001666	432	1,008	182.001666	360	1,080	110.001
600	900	110.003	525	975	35.003	450	1,050	0	375	1,125	0
2,056	3,084	1,305.997334	1,799	3,341	1,048.99733	1,542	3,598	791.997334	1,285	3,855	534.9973
1,688	2,532	3,438.000666	1,477	2,743	3,227.00067	1,266	2,954	3,016.000666	1,055	3,165	2,805.000
1,720	2,580	819.998666	1,505	2,795	604.998666	1,290	3,010	389.998666	1,075	3,225	174.9988
2,376	3,564	765.997666	2,079	3,861	468.997666	1,782	4,158	171.998666	1,485	4,455	0
2,320	3,480	2,060.000666	2,030	3,770	1,770.00067	1,740	4,060	1,480.000666	1,450	4,350	1,190.000
2,032	3,048	5,492.001334	1,778	3,302	5,238.00133	1,524	3,556	4,984.001344	1,270	3,810	4,730.000
1,368	2,052	507.993	1,197	2,223	336.993	1,026	2,394	165.993	855	2,565	0
3,656	5,484	1,505.996334	3,199	5,941	1,048.99633	2,742	6,398	591.996334	2,285	6,855	134.9963
3,536	5,304	666.005334	3,094	5,746	224.005334	2,652	6,188	0	2,210	6,630	0
1,608	2,412	447.998334	1,407	2,613	246.998334	1,206	2,814	45.998334	1,005	3,015	0
2,136	3,204	315.992666	1,869	3,471	48.992666	1,602	3,738	0	1,335	4,005	0
2,024	3,036	723.993334	1,771	3,289	470.993334	1,518	3,542	217.993334	1,265	3,795	0
816	1,224	976.004666	714	1,326	874.004666	612	1,428	772.004666	510	1,530	670.0040
1,232	1,848	732.003	1,078	2,002	578.003	924	2,156	424.003	770	2,310	270.00
1,160	1,740	179.997	1,015	1,885	34.997	870	2,030	0	725	2,175	0
1,816	2,724	585.997666	1,589	2,951	358.997666	1,362	3,178	131.997666	1,135	3,405	0
1,424	2,136	3,414.004666	1,246	2,314	3,236.00467	1,068	2,492	3,058.004666	890	2,670	2,880.00

over wide. So we conclude that in general, the time window width should be controlled within ±10 to ±20 percent.

6. Conclusions

This paper is focused on a multi-objective VRP. To optimize the logistics distribution, we propose a mathematical model with single distribution center and uniform vehicle type, under time window and capacity constraints; and then establish a simulation model specifically for this problem.

According to VRPTW, we adopt object-oriented method to analyze the classes, functions and attributes for all the involved objects; we establish a simulation model with objectification and modularization, which has definite levels, clear logic, and easy expansibility. All flow controls are implemented by JAVA, and can be triggered automatically. The case results indicate the validity of the simulation model.

By introducing random interference factors (i.e. normal traffic flow) into the static VRP model, it is convenient to observe the effect of the crowding level on distribution. This makes it closer to practical distribution systems, and increases the model credibility.

This paper verifies the validity of the simulation model by simulating the cases in AnyLogic software. By running the simulation repeatedly, we analyze key factors, such as the crowding level, time window width and so on. Hence, we propose an advice on the range of parameters related to VRP, which provides certain references for solving the problem and optimizing the distribution.

Table V. Time window width and arrival punctuality

α-%	10	20	30	40	50
OTS	50,025.99	43,701.99	37,377.99	31,639.99	26,660.01

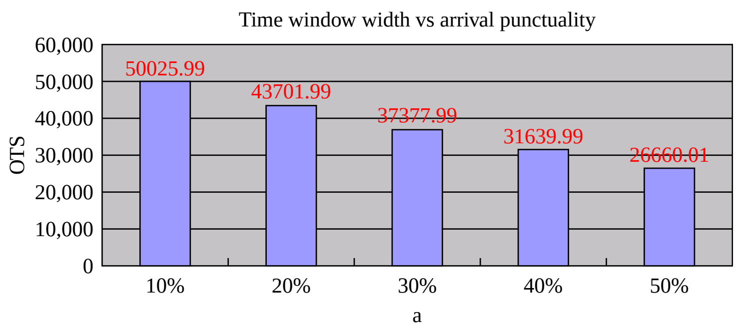


Figure 8. Time window width and arrival punctuality

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