



## Vehicle Routing in Reverse Logistics

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### Abstract

Strong competition has forced many businesses to abandon old logistics practices and concentrated on the forward movement of goods in the supply chain with new ones paying attention to the increased flow of reverse logistics as well.

Many customers having both a pick-up and delivery demand prefer to be served with a single stop (instead of separately for the delivery and pick-up) because of the reduced transport cost and increased customer satisfaction. This situation can be called the vehicle routing problem with simultaneous delivery and pick-up (VRPSDP), opposite to the simple vehicle routing problem (VRP). VRP and VRPSDP are known to be NP-hard problems (Golden et al., 1981; Min, 1989).

VRP with simultaneous delivery and pick-up has been identified as a special research area that has not received sufficient attention in the past. This paper will present a model of VRP with simultaneous delivery and pick-up, highlighting the main differences between traditional vehicle routing problems in forward logistics and those in reverse logistics.

The objective of the problem is to minimise the total costs of transport while satisfying customers' demands of preferred delivery and pick-up conditions (e.g., time periods). The latter act as soft constraints and the aim is to minimise the number of violations in a feasible solution. Main hard constraints in the model regard the limited load capacity, and min loading and unloading durations.. A sample data of eight customers and one warehouse in a small scale grid network is used to test the model. This model will investigate the difference in solution for the VRP with forward and backhaul simultaneously and the VRP without considering backward movement. Sensitivity analysis is conducted with respect to the size and structure of the fleet, location of customers and of the distribution centre in the network.

## **1 Introduction**

Strong competition has forced many businesses to abandon old logistics practices and switch to new ones. Logistics is a "*process of planning, implementing, and controlling the efficient, cost effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements.*" This definition includes inbound, outbound, internal, and external movements, and return of materials for environmental purposes (Council of Logistics Management, 2002).

Logistics is an important component of business strategy (Heskett, 1977). It has the potential to improve a company's competitive position through capability in delivery speed, reliability, responsiveness, and low cost distribution (Morash, Droge, and Vickery, 1996), especially for global manufacturing companies (Fawcett and Gloss, 1993).

Traditionally, companies concentrated on the forward movement of goods in the supply chain. With the increasing flow of products going backward in the chain, companies have to pay attention to reverse logistics as well, as they may significantly reduce the cost of returned merchandise, improve customer satisfaction, and therefore increase the enterprise profit.

Introduction is the first of the five sections of this paper. Section two introduces the importance of Transport in Logistics. Problem description presents in section three. The background and characteristics of the problem and the approaches to solve it will be presented. Section four presents a case study use sample data with the model design and findings will be presented. Section five concludes the paper and future research directions are also addressed.

## **2 Importance of Transport in Logistics**

Within logistics, transport performs a crucial role, from moving raw materials to primary processors (inbound logistics) to delivering finished goods to the point of consumption (outbound logistics). Shipment sizes, routing and scheduling of equipment are key factors in effective management of a firm's transport strategy (Bowersox and Closs, 1996). Effective management implies increasing total utility of the end customers; it comprises four interconnected elements: form, possession, place, and time utility (Coyle, Bardi and Langley, 2003). The first two relate to the product itself and the level of demand for it whereas the latter two govern the location and time availability of the product, and can be directly influenced by transport. Delivering late or to the wrong locations means the customer will not be satisfied and may use alternative services in future.

In general, transport cost is the majority of the total cost in a supply chain. For many companies transport costs comprise approximately 40 to 50% of total

logistics costs and 4 to 10% of the product selling price (Coyle et al., 2003). Although varying significantly across industries and goods, transport optimisation has the potential to reduce the total logistics costs and that is why transport has been investigated as a source of logistics performance. The aim is to create economies of scale and maximise asset utilization. These are not new ideas. Bowersox, Closs, and Stank (1999) claimed that transport efficiency dates back to 3000BC and there are many ways to achieve this goal.

Cubitt (2002) outlined five possibilities for achieving transport efficiency with positive impact on logistics:

- Reducing the number of shippers – increasing the volume of product carried by each shipper;
- Negotiation of rates with carriers – agreeing rates on the basis of the shipper moving a fixed volume;
- Reducing administration costs – linked to reducing shippers as there are fewer companies to deal with;
- Maximising equipment use – optimally routing vehicles as well as ensuring the right vehicle is allocated to each flow;
- Consolidating shipments – creating a full vehicle load by mixing products from different orders/customers.

These can be applied in all areas where transport intervenes in the logistics: inbound logistics, intra-organisational movements, outbound logistics, and recovery and recycling (Figure 1).

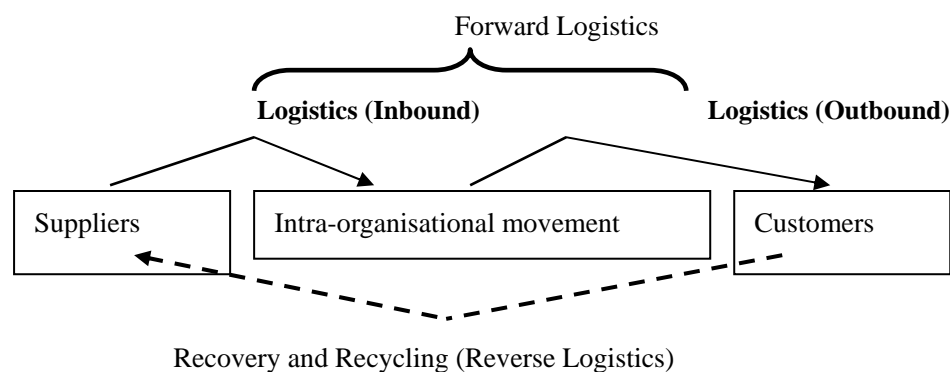


Figure 1 Types of Logistics/Transport Links (Source: Adapted from Monczka, Trent, and Handfield, 2003, pp.550)

While optimising reverse logistics may not deliver the same scale of benefits as forward, plenty of opportunities are still available (Stock, 1992). Harps (2003) found that optimising reverse logistics can result in cost reductions and service level improvements of up to 50 percent.

### 3 Problem Description

Most customers are willing to be served with a single stop with both pick-up and delivery instead of separately trips for the pick-up and delivery because of the reduced transport cost and increased customer satisfaction, thus this kind of situation can be called the VRP with simultaneous delivery and pick-up (VRPSDP) (Dethloff, 2001).

As the VRP is known to be an NP-hard problem (Golden, Ball and Bodin, 1981, Lenstra and Kan, 1981) and, as the VRPSDP is a particular type of VRP, Min (1989) concluded it too is an NP-hard problem.

Bianchessi and Righini (2007) gave a thorough description of VRPSDP which is characterised by:

- A set of customers located on a transport network;
- Each customer  $i$  requires a delivery, a pick-up operation, or both, of a certain amount of goods ( $d_i$ ) or waste ( $p_i$ ) and must be visited once for both operations;
- The service is provided by a set of vehicles of limited capacity  $C$  which means the vehicle cannot carry a total load greater than its capacity at each point on its route;
- Each vehicle leaves the warehouse carrying an amount of goods equal to the total amount it must deliver and returns to the warehouse carrying an amount of waste equal to the total amount it picked up.

VRP is a combinatorial optimisation problem with mixed nature of decisions variables, on which some tailor-made search methods have been developed. A fleet of vehicles supplies customers. Each vehicle has a certain capacity and each customer has a certain demand. Furthermore there exists a warehouse and a distance (length, cost, time) matrix between the customers. It looks for optimal vehicle routes (minimum distance or number of vehicles).

Genetic algorithms are robust, efficient algorithms to search the universe of solutions for a problem based on an evolutionary model (Holland, 1975). Genetic algorithms offer a general-purpose tool for performing search and optimisation functions. The main benefit of GA over other gradient algorithms is that they find good solutions for nonlinear problems by simultaneously exploring search space and exploiting promising areas through mutation, crossover and selection operations (Michalewicz, 1996; Joines, Gupta, Gokce, King and Kay, 2002).

Within the area of logistics, GAs has been used previously. Min et al. (2006) proposed a mathematical model and solution procedure enabling reverse logistics to determine the exact length of holding time for consolidation at the initial collection points and total reverse logistics costs with product returns. The key to finding a good solution using a GA lies in developing a good model

of the problem. A good GA model should reduce or eliminate redundant chromosomes from the population and provide GA operators that effectively improve the population of solutions. The chromosome must accurately represent the problem and allow the GA operators to work effectively on the chromosomes to generate better solutions as the iterative process goes on (Carter, 2003).

This paper presents a GA model based system for Vehicle Routing Problem. In this system vehicles carry goods from a warehouse to multiple customers as well as pick-up goods (recovery or recycle) from customers (reverse logistics process). Planning decisions allocate customer orders to individual vehicles; work out a route for each vehicle. The objective is to minimise the total travel distance. The constraints are the allocation of orders to each vehicle cannot exceed the corresponding load capacity and its arrival time at each customer location shall be within a preferred time period.

#### **4 Implementation and findings**

The model generalise a vehicle delivery routing schedule by utilising built in functions in Excel 2003(Qiu and Zhang, 2006). And Evolver is used to search for the optimal solution. The tool uses genetic algorithms, which are inspired in the laws of natural evolution and produce better solutions from given initial ones through selection, mutation and crossover.

Evolver simply becomes a new submenu option in Excel's Formula menu or the Tools menu of Excel. Genetic algorithms like Evolver require the user to clearly specify the problem as well as a way of evaluating and comparing possible solutions. For Evolver, this is done by creating a model of the problem in Excel. Spreadsheet programs such as Excel provide an excellent environment for creating numerical models in an easy-to-use format.

##### **4.1 Implementation**

This study uses a case to test the model. There are eight customers and one warehouse in a small scale grid network which is used to test the model. This model will investigate the difference in solution for the VRP with forward and backhaul simultaneously and the VRP without considering backward movement. Sensitivity analysis is conducted with respect to the size and structure of the fleet, location of customers and of the distribution centre in the network.

The road network of this case study is as shown in the following table

Warehouse/Customer	X-Coordinate	Y-Coordinate	Order Size(pick-up)	Order Size(Deliver)
1(Warehouse)	10	10		
2	5	5	50	20
3	10	5	20	10
4	15	10	50	20
5	0	10	20	10
6	5	15	20	30
7	10	15	50	40
8	15	20	20	50
9	10	20	50	80

Table 1 Road network for the case study

This model proposes to use three vehicles to deliver the goods to eight customers. For each vehicle it assumes different loading size constraints as follows.  $V_1 \leq 200$  units;  $V_2 \leq 150$  units;  $V_3 \leq 300$  units. The departure time for the three vehicles is the same as at 8:00 in the morning.

Generally assume the  $D_i$  is the total distance of the vehicles move from the warehouse to the customer to deliver and pick-up goods from customer to the warehouse. The  $P_t$  is the penalty of the time window for the vehicles that can not arrive to the customer or to the warehouse on time. Thus, the objective function is to minimise

$$\sum_{i=1}^M D_i \quad \text{and} \quad \sum_{t=1}^M P_t \quad (M \text{ is the number of the vehicles})$$

Subject to limited capacities and travel times

$$\sum_{i=1}^N \sum_{j=1}^N \sum_{k=1}^N C_{ijk} X_{ijk} \quad (\text{Hwang, 2005}).$$

Hwang (2005) used a GA for this mixed integer problem based on improved operators to solve multi-depot routing with time constraints and found the algorithm is efficient.

#### 4.2 Results comparison and findings

##### *Scenario 1 Pick-up and deliver to the customers with different vehicles*

This scenario assumes the vehicle one and vehicle two for forward movement only and vehicle three for backward movement. The prefer time for customers is from 8:00—17:00. Five runs have been carried out with different initial solution points and a solution that has the lowest objective function value (travel cost) of 146 with penalty value of 0, which is likely the optimum or at least a near-optimal solution.

The customer assignments and vehicle loading size for each vehicle are illustrated in table 2.

Route Sequence 1(warehouse)	Customer	Customer Assign to Vehicle		Vehicle Load		
				Vehicle 1	Vehicle 2	Vehicle 3
2	3	1	3	20	0	10
3	2	1	3	50	0	20
4	5	2	3	0	20	10
5	6	1	3	20	0	30
6	4	2	3	0	50	20
7	7	1	3	50	0	40
8	9	2	3	0	50	80
9	8	2	3	0	20	50
				140	140	260

Table 2 The customer assignments and vehicle loading size of three vehicles to scenario 1

The solution of arrival time for eight customers is shown in table3.

	Arrival Time (hour)		
	Vehicle 1	Vehicle 2	Vehicle 3
Customer 2	9:12	/	9:05
Customer 3	8:30	/	8:30
Customer 4	/	10:28	11:20
Customer 5	/	9:42	10:05
Customer 6	10:14	/	10:32
Customer 7	10:35	/	11:52
Customer 8	/	12:12	13:28
Customer 9	/	11:28	12:26

Table 3 Solution of arrival time to scenario 1

*Scenario 2 Pick-up and deliver to the customers with same vehicle simultaneously*

This scenario assumes the three vehicles deliver goods with forward and backward movement at the same time. The prefer time for customers is from 8:00—17:00. A solution has the lowest travel cost of 62 with penalty value 0, which is likely the optimum or at least a near-optimal solution.

The customer assignments and vehicle loading size for each vehicle are illustrated in the following table.

Route Sequence	Customer	Customer Assign to Vehicle		Vehicle 1		Vehicle 2		Vehicle 3	
1(warehouse)				Deliver	Pick-up	Deliver	Pick-up	Deliver	Pick-up
2	7	3	3	0	0	0	0	50	40
3	9	1	1	50	80	0	0	0	0
4	6	3	3	0	0	0	0	20	30
5	2	3	3	0	0	0	0	50	20
6	8	1	1	20	50	0	0	0	0
7	4	2	2	0	0	50	20	0	0
8	3	2	2	0	0	20	10	0	0
9	5	3	3	0	0	0	0	20	10
				200		100		240	

Table 4 The customer assignments and vehicle loading size of three vehicles to scenario 2

The solution of arrival time for eight customers is shown as following table.

	Arrival Time (hour)		
	Vehicle 1	Vehicle 2	Vehicle 3
Customer 2	/	/	10:44
Customer 3	/	10:03	/
Customer 4	/	8:30	/
Customer 5	/	/	11:46
Customer 6	/	/	9:54
Customer 7	/	/	8:30
Customer 8	10:32	/	/
Customer 9	9:00	/	/

Table 5 Solution of arrival time to scenario 2

Obviously, scenario 2 is better than scenario 1 because vehicle three can not only deliver goods but also backhaul them from customers. This can maximise the vehicle utilisation and leads to reduce travel cost.

*Scenario 3 Compare the results on above two scenarios with a smaller order size*

Case 1: The best solution has the lower objective function value of 77 than that of scenario 1 and no penalty value. The customer assignments and vehicle loading size for each vehicle are illustrated in the following table.

Route Sequence 1(warehouse)	Customer	Customer Assign to Vehicle		Vehicle Load		
				Vehicle 1	Vehicle 2	Vehicle 3
2	6	1	3	6	0	0
3	7	1	3	10	0	10
4	4	2	3	0	3	0
5	3	2	3	0	2	0
6	9	1	3	2	0	0
7	2	2	3	0	10	2
8	8	1	3	10	0	0
9	5	2	3	0	5	0
				28	20	12

Table 6 The customer assignments and vehicle loading size of three vehicles to scenario 3 (case 1)

**Case2:** This scenario uses one vehicle for deliver and backhaul because of smaller order size of goods. The best solution has a higher objective function value of 67 without penalty value than that of scenario 2. But the travel cost is lower than case 1 in scenario 3. This scenario only needs one vehicle for pick-up because of a smaller total order size of goods. This demonstrates that the GA model can automatically scale down the requirement of vehicles if customer demand is not high.

Route Sequence 1(warehouse)	Customer	Customer Assign to Vehicle		Vehicle 1		Vehicle 2		Vehicle 3	
				Deliver	Pick-up	Deliver	Pick-up	Deliver	Pick-up
2	3	1	1	2	0	0	0	0	0
3	2	1	1	10	2	0	0	0	0
4	5	1	1	5	0	0	0	0	0
5	6	1	1	6	0	0	0	0	0
6	7	1	1	10	10	0	0	0	0
7	4	1	1	3	0	0	0	0	0
8	9	1	1	2	0	0	0	0	0
9	8	1	1	10	0	0	0	0	0
				60		0		0	

Table 7 The customer assignments and vehicle loading size of three vehicles to scenario 3 (case 2)

	CASE1:Arrival Time (hour)			CASE2:Arrival Time (hour)		
	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 1	Vehicle 2	Vehicle 3
Customer 2	/	10:00	10:01	9:01	/	/
Customer 3	/	9:31	/	8:30	/	/
Customer 4	/	8:30	/	11:11	/	/
Customer 5	/	10:27	/	10:02	/	/
Customer 6	9:00	/	/	10:25	/	/
Customer 7	9:33	/	8:30	10:39	/	/
Customer 8	10:18	/	/	11:43	/	/
Customer 9	10:03	/	/	11:58	/	/

Table 8 Arrival time comparison to scenario 3

Table 8 shows the comparison of arrival time in these two cases.

*Scenario 4 Compare the results on above two scenarios with narrow time windows*

The prefer time for customers and solutions are show as following tables

Customer	Prefer time	
Customer 2	8	12
Customer 3	8	13
Customer 4	9	12
Customer 5	8	17
Customer 6	12	17
Customer 7	12	17
Customer 8	12	17
Customer 9	12	17

Table 9 Customers' prefer time

Route Sequence 1(warehouse)	Customer	Customer Assign to Vehicle		Vehicle Load		
				Vehicle 1	Vehicle 2	Vehicle 3
2	4	2	3	0	50	20
3	3	2	3	0	20	10
4	2	2	3	0	50	20
5	5	1	3	20	0	10
6	6	1	3	20	0	30
7	7	1	3	50	0	40
8	9	1	3	50	0	80
9	8	1	3	20	0	50
				160	120	260

Table 10 The customer assignments and vehicle loading size of three vehicles to scenario 4 (case1)

Route Sequence 1(warehouse)	Customer	Customer Assign to Vehicle		Vehicle 1		Vehicle 2		Vehicle 3	
				Deliver	Pick-up	Deliver	Pick-up	Deliver	Pick-up
2	5	3	3	0	0	0	0	20	10
3	4	1	1	50	20	0	0	0	0
4	6	3	3	0	0	0	0	20	30
5	9	3	3	0	0	0	0	50	80
6	7	1	1	50	40	0	0	0	0
7	3	2	2	0	0	20	10	0	0
8	2	2	2	0	0	50	20	0	0
9	8	3	3	0	0	0	0	20	50
				160		100		280	

Table 11 The customer assignments and vehicle loading size of three vehicles to scenario 4 (case2) After several runs, the solution of case 1 get the objective function value of 133 with penalty value 11.65. The lowest objective function value of case 2 is 81 and the penalty value is 12.16. The huge penalty value is the result of the time constraints can not be satisfied totally.

	CASE1:Arrival Time (hour)			CASE2:Arrival Time (hour)		
	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 1	Vehicle 2	Vehicle 3
Customer 2	/	10:21	10:05	/	9:17	/
Customer 3	/	10:00	9:42	/	8:30	/
Customer 4	/	8:30	8:30	8:30	/	/
Customer 5	9:42	/	10:38	/	/	9:42
Customer 6	10:17	/	11:03	/	/	10:19
Customer 7	10:39	/	11:32	10:03	/	/
Customer 8	12:03	/	13:07	/	/	12:42
Customer 9	11:19	/	12:05	/	/	11:09

Table 12 Arrival time comparison to scenario 4

Table 12 shows the comparison of arrival time in these two cases.

## 5 Conclusions and Recommendations

This paper reviewed the importance of reverse logistics and VRPSDP background. The approaches used previously were introduced and discussed. A case study with small size data is carried out to test different scenarios in this problem. The case study demonstrates that the model is sensitive to a variety of situations in delivering customer orders with different order sizes and different patterns of the time windows that customers prefer. The most important thing is it demonstrates the pick-up and backhaul goods simultaneously can definitely reduce the travel cost. It has better result with forward and backward movements separately.

Since the real life problems are large and have NP hard complexity, the GA will solve the model efficiently. The objective function will include minimum recycle time (comprising return handling) and minimum environmental costs. Further work will extend the model for large size problem in real world. The future research will advance the application of GA of VRPSDP by integrating forward and reverse logistics for pick-up and delivery concurrently with consider heterogeneous vehicles with different types of goods in the deliveries and pick-ups.

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