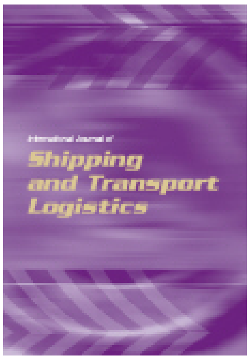

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Using the route planning for supplying spare parts to reduce distribution costs: a case study in a roadside assistance company

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Using the route planning for supplying spare parts to reduce distribution costs: a case study in a roadside assistance company

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Abstract: In this study, a distribution model has been proposed to optimise the transportation, inventory, and shortage costs for the delivery of spare parts to roadside assistance cars. The model is based on the travelling salesman problem (TSP), where we have added a function to optimise distribution days. The model has been used in a real case for a roadside assistance company with 36 roadside assistance cars. In the company's current plan, each car visits the company's warehouse every five days to pick up spare parts. Using a delivery truck is proposed to deliver spare parts to the roadside assistance cars. Based on this proposal, a model was developed to reduce distribution costs by choosing the optimal delivery route and distribution days. The proposed plan has reduced the distribution cost by more than 50% compared with the current distribution plan used by the company.

Keywords: distribution spare parts; route planning; travelling salesman problem; TSP; inventory routing problem; IRP; roadside assistance; distribution cost.

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1 Introduction

In 2020, more than 77 million motor vehicles were sold worldwide (OICA, 2021). Based on the same report, in 2020, more than 1,590 million cars were being used, which grew on average annually by 4%. Providing after-sale services for all these cars can play a significant role in customers choosing their automotive company. Nowadays, after-sale services are a revenue-generative, profitable activity, and competitive advantage in most manufacturing industries (Gaiardelli et al., 2007). The profit of after-sale services is often more than the profit of goods, and the markets of after-sale services are usually four to five times larger than the product's market (Bundschuh and Theodore, 2003). The automotive industry is not exceptional from this rule, and the volume of the market of after-sale services is considerable. Therefore, the after-sale services market can be considered an advantage for competition among large automotive companies.

When the cars cannot go to a repair shop, a technician can visit them at the place and perform the repair. Naturally, then, roadside assistance is one of the favourite services which are usually asked for by customers. However, providing on-site repair has a significant cost for the roadside assistance companies. Sometimes the on-site repair is impossible because the roadside assistance cars lack enough equipment and tools. However, a company can provide better services for customer satisfaction while decreasing the service costs, among which on-site services are considered one of the essential parameters for customer satisfaction. In this regard, automotive companies strive to provide better and more competitive services to maintain their markets.

The roadside assistance cars should have enough spare parts, equipment, and tools to provide better and faster on-site service to customers. However, there is a conflict between the number of spare parts, tools, and equipment. Since enough space is not available in the roadside assistance car, an increase in the number of parts leads to a decrease in the number of tools and equipment. Therefore, increasing the number of tools and equipment by decreasing the number of spare parts can sometimes lead to providing more services by the roadside assistance cars. For example, by removing a car battery with a weight of about 20 kilograms and dimensions of approximately 20 × 30 × 20 cm from the list of spare parts, it is possible to add a portable air pump with an approximate weight of 6 kilograms and dimensions of 15 × 40 × 33 cm as equipment, which can be used to repair of car puncture.

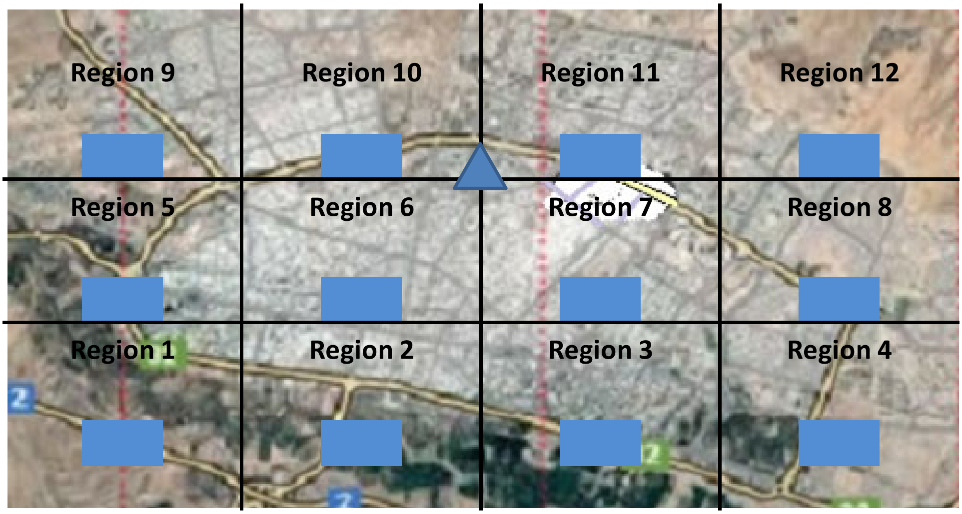
Cost reduction is a significant factor for roadside assistance companies. Therefore, they should decrease costs to compete with other competitors by using different reduction solutions like decreasing spare parts prices, costs of employees, and transportation costs. The present study aimed to reduce the costs of supplying spare parts for roadside assistance cars. As a result, the total costs will decrease, although our proposed method may sometimes increase shortage costs in roadside assistance cars.

This research investigates three major distribution costs, including transportation, inventory, and shortage cost. In the following sections, the distribution problem is discussed, and then the literature review about current distribution methods is presented. In addition, we explain the proposed method and estimate the cost associated with the proposed method. Eventually, sensitivity analysis is presented.

1.1 Problem statement

In the case study investigated in this research, 36 roadside assistance cars in a small city provide services to customers in 12 regions (as shown in Figure 1). When the roadside assistance car starts a shift, it is in its region on the determined location that the roadside assistance company has already specified. In the existing method, each roadside assistance car must go to the central warehouse and pick up spare parts every five days. According to the rules, each roadside assistance car can have a specific number of spare parts to provide the requested services. However, it assumes that the roadside assistance car can only visit the warehouse every five days. Thus, the company should deliver spare parts to the roadside assistance cars if they face a shortage, which causes extra costs for the company.

Figure 1 The specified regions by the company (see online version for colours)



Although there are many costs for supplying spare parts, this company focuses on transportation, inventory, and shortage costs in roadside assistance cars. For example, we do not consider spare parts' price because it exists in any supplying method. In the following, each cost is explained.

1 *Transportation cost*: Each roadside assistance car should go to the warehouse to pick up the parts. This commute has a cost for the roadside assistance cars and their company. However, the transportation cost decreases by using the proposed method while decreasing their commuting cost.

2 *Inventory cost*: Each spare part is stored by roadside assistance cars from the time it is stored in the roadside assistance car until it is used in the customer's car. The warehouse's ordering system is not considered in this study, and this study focuses on keeping spare parts in roadside assistance cars. Changing the distribution plan can only affect the time that the part is kept in the roadside assistance cars. The cost of keeping the parts in roadside assistance cars is linked to the consumed gasoline, theft risk, and occupied space in the car. The company can add new tools and equipment and provide new services to its customers if they decrease the number of spare parts in the roadside assistance car.

3 *Shortage cost*: The shortage occurs when the spare parts in the roadside assistance car are less than the received demand, and the company must cover this problem by sending a courier from the warehouse to the roadside assistance car. Of course, roadside assistance cars, which work in the same regions, can swap spare parts

without a considerable cost in this condition. Thus, the shortage cost happens when all roadside assistance cars in the region have no spare parts. The assumption is that one courier can only carry one spare part. Therefore, the shortage cost of each spare part is the same as the cost of delivering by courier.

The main problem is to reduce the cost of distribution of spare parts by changing the supply plan. This study used the route planning approach to deliver spare parts to the roadside assistance cars. Thus, instead of picking up spare parts by roadside assistance cars from the warehouse, they are delivered by a delivery truck. In this regard, the following assumptions are considered;

1. In the existing method, each roadside assistance car should go to the warehouse to pick up spare parts enough for 5 days.
2. The city is divided into 12 equal regions
3. A spot in the region is the primary location at the start of the shift. Therefore, the spare parts will be delivered to roadside assistance cars by the delivery truck to this location.
4. The distance between regions is calculated orthogonally.
5. The network of ways among regions and the warehouse is complete.
6. The company specifies the number of roadside assistance cars in each region.
7. The existing method is compared with the proposed method using transportation, inventory, and shortage cost.
8. The swapping of spare parts between two roadside assistance cars is not considered if they are in two different regions.

1.2 Model's parameters

In this article, a case of roadside assistance services is studied for a roadside assistance company that provided the data. Unfortunately, we cannot use the original data for this case because of confidential data. Nevertheless, the presented data in the following tables, generated by the company's experts, have the original data's structure and closely resemble the original data. So these data have been extracted from the original data and have preserved their structures. Table 1 shows each roadside assistance car's estimated supplies (packages) needed for five days. These spare parts should be delivered daily to the roadside assistance cars.

Table 2 shows the location of each roadside assistance car in regions. In some regions, more than one car may be allocated since the demand for services in that region is more than the others.

Tables 1 and 2 indicate each region's demand, and Table 3 summarises the demand for roadside assistance cars in each region.

Table 1 Estimated daily demands of spare parts for roadside assistance cars

		Roadside assistance car's number																																				
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*	*36*	*Total*
Days	1	17	25	21	15	23	20	16	19	19	18	22	24	19	19	18	24	23	21	23	19	24	20	20	16	22	17	21	18	18	19	16	25	15	20	21	18	715
	2	22	22	20	22	17	23	25	18	24	17	18	25	21	21	23	16	17	24	19	15	25	19	18	23	15	19	20	15	15	18	16	19	16	15	24	22	708
	3	18	20	22	21	20	21	22	22	19	22	23	21	18	25	22	25	22	23	15	15	22	25	22	22	19	22	18	25	24	25	17	23	23	24	19	24	770
	4	17	25	25	25	18	21	24	16	20	18	21	24	21	25	24	24	20	17	16	21	23	24	25	19	21	16	23	18	25	25	24	20	20	23	17	23	768
	5	25	16	15	16	23	16	17	24	16	16	22	15	17	23	19	25	20	22	16	19	19	25	20	23	21	22	22	24	25	15	19	19	17	20	15	17	705
	Total	99	108	103	99	101	101	104	99	98	91	106	109	96	113	106	114	102	107	89	89	113	113	105	103	98	96	104	100	107	102	92	106	91	102	96	104	3,666

Table 2 The allocated roadside assistance cars for regions

Regions' number	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Car's number	3 29 2 16 23	27	13 8 1	18 22 35	6 33 32	10 34 17	36 30	19 20	24 25 9	28 12 14 5	15 31 11 26	4 21 7

Table 3 The aggregate region demand for each day

		Days				
		1	*2*	*3*	*4*	*5*
Regions	1	108	91	113	124	101
	2	21	20	18	23	22
	3	55	61	58	54	66
	4	62	67	67	58	62
	5	60	58	67	61	52
	6	61	49	68	61	56
	7	37	40	49	48	32
	8	42	34	30	37	35
	9	57	62	60	60	60
	10	84	78	91	85	85
	11	73	76	84	85	82
	12	55	72	65	72	52
	Total	715	708	770	768	705

Table 4 The distances between regions (0 is the warehouse)

Regions	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
0	0	155	105	105	155	115	65	65	115	75	25	25	75
1	155	0	40	20	150	40	90	140	190	80	130	180	230
2	105	40	0	50	100	90	40	90	140	130	80	130	180
3	105	20	50	0	50	140	90	40	90	180	130	80	130
4	155	150	100	50	0	190	140	90	40	230	180	130	80
5	115	40	90	140	190	0	50	100	150	40	90	140	190
6	65	90	40	90	140	50	0	50	100	90	40	90	140
7	65	140	90	40	90	100	50	0	50	140	90	40	90
8	115	190	140	90	40	150	100	50	0	190	140	90	40
9	75	80	130	180	230	40	90	140	190	0	50	100	150
10	25	130	80	130	180	90	40	90	140	50	0	50	100
11	25	180	130	80	130	140	90	40	90	100	50	0	50
12	75	230	180	130	80	190	140	90	40	150	100	50	0

As shown in Table 4, the Euclidean distance is observed between each region with others and the warehouse. These distances were determined by measuring the distance between the centre of the regions; if we consider the transportation cost per unit of distance equal to 10 monetary units, the cost matrix will be obtained by multiplying the distance matrix by 10.

Table 5 indicates the information related to the received actual demands for roadside assistance cars. The company calculates each region's inventory and daily shortages (Tables 3 and 5).

Table 5 The actual daily consumption in each region

		Days				
		1	*2*	*3*	*4*	*5*
Regions	1	106	88	118	131	95
	2	23	21	22	18	19
	3	51	73	56	51	62
	4	64	70	67	53	66
	5	63	55	66	59	60
	6	66	48	67	58	54
	7	41	42	49	45	31
	8	45	38	31	37	36
	9	66	73	57	59	47
	10	97	79	80	87	79
	11	77	86	86	83	81
	12	50	67	79	76	54
	Total	749	740	778	757	684

2 Literature review

The research conducted in our study can be classified into three groups:

2.1 To optimise spare parts distribution costs

According to our knowledge, there is not sufficient resource about this topic. We are aware of only two articles that consider optimising distributing spare parts. First, Shafaei and Akbari Jokar (2021) compared the referral to the warehouse with the truck distribution. In their proposed method, a delivery truck distributes the spare parts daily among roadside assistance cars by finding the optimum route. Their method can reduce the total cost of supplying spare parts by up to 20%. In the second paper, Kargari and Sepehri (2012) found a decrease in the transportation cost of distributing spare parts by clustering retailers with a data mining approach, which their approach is mainly different from ours.

2.2 Distribution of spare parts

The second group of the current studies is articles in which their primary subjects are the distribution of spare parts, but they follow objects which are different from cost optimisation. For example, García-Benito and Martín-Peña (2021) improved the maintenance and overhauling in a section of the Spanish military by improving the distribution methods of spare parts in the two-echelon supply system. In addition, Sleptchenko et al. (2005) focused on decreasing inventory investment in spare part networks and used a prioritisation model in their research. Campbell et al. (2008) distributed essential items among injured people after a disaster by using a VRP model and considering both minimum cost and access time to the items by the injured people. Davoodi and Goli (2019) minimised the arrival time to disaster locations by roadside assistance cars and developed an integrated model for roadside assistance operations in crisis conditions. Chang et al. (2007) developed a stochastic model for locating the main camps and covered the optimal distribution among other camps while facing a flood crisis to minimise average transportation distances in the crisis condition. All of the above studies used the VRP approach for distributing some items among users. We have used the same approach in this study.

2.3 Combination of the VRP with inventory management

The third group of the literature review is the articles concerned with combining VRP and inventory management optimisation, which has been discussed as inventory routing problem (IRP). According to Coelho et al. (2014), Bell et al. (1983) were the first group to propose IRPs in 1983. The IRP is related to vendor-managed inventory (VMI), which is studied in supply chain management.

Anialy (1994) studied IRP by distributing the commodities from one warehouse to *n* retailer to minimise the average transportation and holding costs in the long run. Prutsakul (1998) presented a kind of IRP to find a replenishment policy for retailers using the depot and multi-retailer systems to minimise transportation and inventory costs. Bard (1998) developed a solving method based on the decomposition method for IRP by selecting customers to visit each day, assigning each customer to each route, and specifying the route and sequencing for visiting each customer to minimise annual delivery costs. Kleywegt et al. (2004) developed a dynamic programming method for solving a stochastic IRP using a Markov decision process model for formulating a stochastic IRP and proposed an approximation method for finding a solution. Chiou (2005) worked on inventory and routing problems by considering lead time due to traffic congestion and proposed a new class of strategies for inventory replenishment for each retailer in the delivery systems managed by the distributor. Like the customary objective of these models, minimising the total inventory and transportation costs is considered the model objective in her study. Sakiani et al. (2021) presented a mathematical model to schedule the distribution and redistribution of relief goods among people in the post-disaster environment. They used a specialised simulated annealing algorithm to solve the model.

Aghezzaf et al. (2006) focused on a distribution centre and a set of vendors with their demand rates in the supply chain of high-consumption products. They proposed an IRP model to determine a distribution plan for minimising average total distribution and inventory holding costs without causing a stock-out at any vendors during a given planning horizon. In addition, the proposed model extended the concept of vehicle routes to vehicle multi-tours (Aghezzaf et al., 2006).

Archetti et al. (2007) used a branch-and-cut algorithm to solve an IRP model in a distribution problem. Shipping products from one supplier to retailers was considered in a given time horizon. The supplier monitored the inventory level of retailers and determined its replenishment policy (using the VMI technic). Determining each district's time, the quantity of shipping to each retailer, and the limited capacity of vehicle routes were considered the main problems (Archetti et al., 2007).

Michel and Vanderbeck (2012) presented an application of the IRP in the tactical stage planning of single-product picks up over time. They used a column-generation approach for solving the model to minimise the time between two visits to each customer by vehicle (Michel and Vanderbeck, 2012). In another study, Le et al. (2012) proposed a column generation-based heuristic algorithm for an IRP model with perishable goods to minimise transportation and inventory costs. They also added cutting planes to improve the formulation (Le et al., 2012).

Bertazzi and Speranza (2013) presented a tutorial paper to introduce the classification of IRPs by discussing the basic IRP and developing the expansion of this problem to the multi-vehicle state.

Ekici et al. (2015) investigated a condition of IRP in which a vendor is responsible for replenishment inventory to a set of customers to minimise transportation costs delivered to the customers from the warehouse by clustering customers and scheduling to solve the problem.

Hemmati et al. (2015) considered a VMI service in tramp shipping and proposed a heuristic method to determine the routes and schedules for a shipping company, and solved a combined cargo and IRP by using an effective heuristic. Hemmati et al. (2016) also considered a multi-product short sea inventory-routing problem by using a two-phase matheuristic method for solving the problem and modifying it iteratively based on the information obtained during the process. The model objective was to minimise transportation and port operating costs (Hemmati et al., 2016). Vadseth et al. (2021) presented an iterative matheuristic for solving an IRP model with the maximum level replenishment policy to minimise inventory costs and transportation costs for both customers and suppliers. Mardani and Zegordi (2017) presented an approach to integrating production and distribution scheduling for perishable goods. They evaluated the relationship between the production of perishable products and the effectiveness of fast distribution on their quality. In addition, they used the vehicle routing concept to distribute goods among customers to decrease total delivery time (Marandi and Zegordi, 2017).

Xie et al. (2016) developed a large-scale mixed-integer mathematical model for infrastructure planning of mechanical work facilities, which is vital for increasing railroad efficiency in North America. The model integrated and optimised some decisions about facilities. The essential decisions included locations, capabilities, and capacities of all facilities, routing plans for moveable facilities, and assigning each locomotive to facilities (Xie et al., 2016).

Crama et al. (2018) evaluated an IRP model with stochastic demand for the perishable product. They developed a solution to this problem, aiming to maximise the expected profit obtained by the new delivery quantity to the stores (Crama et al., 2018).

Chitsaz et al. (2019) combined the assembly production with the routing problem and introduced the assembly routing problem (ARP) and formulated this problem as a mixed-integer linear program, and proposed a metaheuristic solution, the objective of which was to minimise the total production, setup, holding, and transportation costs. The holding costs included inventory at the supplier and plant (Chitsaz et al., 2019).

Widyadana and Irohara (2019) focused on a multi-tour inventory routing for deteriorating items like foodstuffs or electrical products that spoiled over time and used the metaheuristic method, particle swarm optimisation (PSO), to find a near-optimum solution for an IRP model with time windows.

Coelho et al. (2020) presented a multi-attribute inventory problem formulated by a mathematical model. The research included a subset of the VMI strategy. It used an exact algorithm to solve the problem and introduced an exact hybrid method to minimise the total inventory and transportation costs (Coelho et al., 2020).

Although there are many studies about IRP, to the best of our knowledge, no investigation has addressed the IRP by supplying spare parts with a delivery truck for roadside assistance cars.

2.4 Summarising and contributions

Based on the studies mentioned above have concentrated only on:

1. using a route planning approach for distributing spare parts
2. optimising spare parts distribution with different objectives
3. optimisation of routing and inventory management simultaneously.

However, in our study, many contributions, as mentioned below, distinguish our study from previous works:

1. The spare part distribution between roadside assistance cars has been investigated in this study for the first time. Notice that the roadside assistance cars are not fixed and moving in their regions.
2. There is no adding shortage cost to the objective function in previous studies, so simultaneously considering travelling/inventory and shortage cost is another contribution of this research.
3. Inventory and shortage costs are connected with the cost of roadside assistance cars in this work, while in previous work, these issues have been considered in the cost of distribution warehouses.
4. Usually, in the route planning approach, the distribution period is given. However, in this study, the distribution days are extracted by the proposed model, and we recognise what days the truck should distribute spare parts.
5. Another contribution of this article is converting the nonlinear model to two linear models by considering an assumption.

More defined models have tried to minimise inventory and transportation costs, while, in this study, the shortage cost was added to the objective since roadside assistance cars do not have spare parts for serving customers. Therefore, the main innovation of this study includes adding the shortage cost with transportation and inventory costs into the objective function simultaneously and using the route planning approach to distribute spare parts among roadside assistance cars.

3 Existing method and its cost

Three kinds of costs are considered to compare the existing and proposed methods.

3.1 Transportation cost

In the existing method, each roadside assistance car goes to the warehouse at the end of the fifth day and picks up its spare parts. Thus, the transportation cost for each car should be calculated first, and then all of them should sum to calculate the transportation costs based on equation (1).

$$C1 = 2 * \sum_{i=1}^{36} C_{i0} \tag{1}$$

where C_{i0} shows the cost between the indicated location for the roadside assistance cars in region *i* and the warehouse. We assume the roadside assistance cars are located in the middle of the bottom edge of the region before going to the warehouse and returning to the same location after picking up the spare part. *Cd* indicates the cost of transportation per distance unit, which is equal to 10 monetary units in this study, so the C_{i0} values are obtained by multiplying *Cd* by the first line of Table 4. Using equation (1), the transportation costs are 64,200 monetary units for 36 roadside assistance cars.

3.2 Inventory costs in the roadside assistance cars

When a roadside assistance car goes to the warehouse and picks up spare parts, it takes enough supplies for five days. The roadside assistance car uses the first-day portion of spare parts, and the remaining parts inevitably hold in the car for four days. On the second day, the roadside assistance car uses spare parts the same way and holds on to the remaining spare parts for three days. Accordingly, the spare parts are used by each roadside assistance car until the end of the fifth day. Equation (2) calculates the inventory costs.

$$C2 = \sum_{i=1}^{12} \sum_{t=1}^{5} Ci * In_{it} \tag{2}$$

where In_{it} shows the amount of inventory in region *i* for the day *t*. The amount can be calculated using the well-known inventory formula [*final inventory* (*shortage*) = *beginning inventory* + *input inventory* – *output inventory*] based on Tables 1 and 3, shown in Table 6. The *Ci* is the cost of inventory in the car per day, which is 10 monetary units in this case study. To calculate inventory and shortage, we assume that the roadside assistance cars in each region can circulate spare parts among themselves. As shown in Table 6, there are 7,140 units of inventory in the roadside assistance cars over five days, and the total inventory cost is 71,400 monetary units. In the existing method, we observe the exceeding inventory in the cars in the early days, and the shortages usually are zero because each car picks up the total spare parts for all days on the first day.

3.3 Shortage costs in the roadside assistance cars

When a roadside assistance car runs out of spare parts for a considerable period, it faces a shortage of inventory, where the roadside assistance company should send replacement parts to cover the shortage of the spare part. Equation (3) calculates the shortage cost.

$$C3 = Cs * \sum_{i=1}^{12} \sum_{t=1}^{5} S_{it} * ds_{i0} \tag{3}$$

where S_{it} indicates the number of shortages in the region i for the day t, ds_{i0} shows the distance of region i from the warehouse (0), Cs is the cost of sending a part to the roadside assistance car per distance unit and is considered 5 in this case study. The same Equation is used as the previously applied section for inventory to calculate the shortages in each region, which results are shown in Table 7. Using Table 7 and equation (3), the shortage cost is 19,075 monetary units. As indicated in Table 7, the shortage costs only happened on the last day of the period since the inventory of previous days covers all shortages except the shortage on the last day.

Table 6 The aggregated roadside assistance cars inventory in each region

		Days					
		1	*2*	*3*	*4*	*5*	*Total*
Regions	1	431	343	225	94	0	1,093
	2	81	60	38	20	1	200
	3	243	170	114	63	1	591
	4	252	182	115	62	0	611
	5	235	180	114	55	0	584
	6	229	181	114	56	2	582
	7	165	123	74	29	0	391
	8	133	95	64	27	0	319
	9	233	160	103	44	0	540
	10	326	247	167	80	1	821
	11	323	237	151	68	0	779
	12	266	199	120	44	0	629
	Total	2,917	2,177	1,399	642	5	7,140

Table 7 The aggregated roadside assistance cars shortage in each region

		Days					
		1	*2*	*3*	*4*	*5*	*Total*
Regions	1	0	0	0	0	1	1
	2	0	0	0	0	0	0
	3	0	0	0	0	0	0
	4	0	0	0	0	4	4
	5	0	0	0	0	5	5
	6	0	0	0	0	0	0
	7	0	0	0	0	2	2
	8	0	0	0	0	9	9
	9	0	0	0	0	3	3
	10	0	0	0	0	0	0
	11	0	0	0	0	13	13
	12	0	0	0	0	10	10
	Total	0	0	0	0	47	47

The total cost of the current method used by the roadside assistance company can be computed by summation of the transportation, inventory, and the shortage cost;

$$\begin{aligned} &\textit{Total cost of current method} = C1 + C2 + C3 \\ &= 64200 + 71400 + 19075 = 154675 \ (\textit{monetary units}) \end{aligned}$$

4 The proposed method and estimating its cost

The proposed method is based on the concept of vehicle routing, which the roadside assistance company accepts to deliver the items at shorter intervals instead of storing them in the car for five days. As a result, the inventory cost will be lower, although the transportation cost can increase because of the number of days when supply arises. Furthermore, in the proposed method, the spare parts in the roadside assistance cars become less, therefore decreasing the inventory costs. However, the actual demand may exceed the expected demand and impose a shortage cost.

Based on the travelling salesman problem (TSP) concept, when a delivery truck is responsible for distributing the parts among the roadside assistance cars, the transportation costs and cost of supplying spare parts for the roadside assistance cars can be reduced. In addition, the supply cost can be reduced when the required parts are distributed daily instead of every five days. However, there seem to be optimum delivery days between these two states. Therefore, the proposed model finds the optimum delivery days for the spare parts to be distributed.

This model is also designed to make an optimum decision to find a suitable supply route and reduce transportation, inventory, and shortage costs. The following symbols are used to formulate the proposed model:

n	number of provided locations (equal 13 in this case study)
m	number of days for planning (equal 5 in this case study)
d_{it}	expected amount of demand at location *i* for day *t* (Table 3.)
d'_{it}	amount of order to be shipped location *i* for day *t* (Table 5)
C_{ij}	cost of moving between locations *i* and *j* (Table 5 multiplied by *Cd* = 10)
Ci	cost of inventory unit per day (equal 10 in this case study)
Cs	cost of providing a shortage unit (equal to 5 in this case study).

It should be noted that zero (0) for *i* and *j* represents the warehouse location where the delivery truck is stationed.

In addition, decision variables for the model are defined in the following:

$X_{ijt} = 1$ if the delivery truck goes from location *i* to *j* on day *t*; otherwise, zero

$Y_{itk} = 1$ if the orders of location i are delivered for day *k* on day *t*; otherwise, zero.

In this case, the inventory or the shortage in each region is a dependent variable affected by the distribution time.

D_{it} total orders in location *i*, which should be satisfied on day *t*

In_{it} inventory in location *i* at the end of day *t*

S_{it} shortages in location *i* on day *t*

u_{it} extra variable for location *i* in day *t* for elimination sub tours $i = 1, 2, \ldots, n$ and $t = 1, 2, \ldots, m$.

The objective of the model aims to minimise transportation, inventory, and shortage cost based on equation (1).

$$Min\ Z = \sum\nolimits_{i=0}^{n} \sum\nolimits_{j=0}^{n} \sum\nolimits_{t=1}^{m} C_{ij} X_{ijt} + \sum\nolimits_{i=2}^{n} \sum\nolimits_{t=1}^{m} Ci * In_{it} + \sum\nolimits_{i=2}^{n} \sum\nolimits_{t=1}^{m} Cs * S_{it} \tag{4}$$

The first part of equation (4) calculates the transportation costs, and the second part calculates the inventory cost during the given period. Finally, the shortage cost is calculated by the third part of the equation.

Further, the constraint equations are defined as follows.

$$\sum\nolimits_{j \neq i}^{n} \left(X_{ijt} + X_{jit} \right) \leq D_{it} \qquad i = 0, 2, \ldots, n \quad t = 1, 2, \ldots, m \tag{5}$$

$$\sum\nolimits_{j \neq i}^{n} X_{ijt} \leq 1 \qquad i = 0, 2, \ldots, n \quad t = 1, 2, \ldots, m \tag{6}$$

$$\sum\nolimits_{i \neq j}^{n} X_{jit} \leq 1 \qquad j = 0, 2, \ldots, n \quad t = 1, 2, \ldots, m \tag{7}$$

$$\sum\nolimits_{k \geq t}^{m} d'_{ik} y_{itk} = D_{it} \qquad i = 1, \ldots, n \quad t = 1, 2, \ldots, m \tag{8}$$

$$\sum\nolimits_{t=1}^{k} y_{itk} = 1 \qquad i = 1, \ldots, n \quad k = 1, 2, \ldots, m \tag{9}$$

$$In_{it} = In_{i,t-1} + D_{it} - d_{it} \qquad i = 1, \ldots, n \quad t = 1, 2, \ldots, m \tag{10}$$

$$S_{it} = d_{it} - In_{i,t-1} - D_{it} \qquad i = 1, \ldots, n \quad t = 1, 2, \ldots, m \tag{11}$$

$$D_{it} + In_{i,t-1} - d_{it} + S_{it} = 0 \qquad i = 1, \ldots, n \quad t = 1, 2, \ldots, m \tag{12}$$

$$\sum\nolimits_{i=1}^{n} X_{i0t} \leq 1 \qquad t = 1, 2, \ldots, m \tag{13}$$

$$\sum\nolimits_{j=1}^{n} X_{0jt} \leq 1 \qquad t = 1, 2, \ldots, m \tag{14}$$

$$\sum\nolimits_{i=1}^{n} X_{0jt} = \sum\nolimits_{j=1}^{n} X_{0jt} \qquad t = 1, 2, \ldots, m \tag{15}$$

$$u_{it} - u_{jt} + (n-1) x_{ijt} \leq (n-2) \quad i, j = 1, \ldots, n \quad t = 1, 2, \ldots, m \tag{16}$$

$$1 \leq u_{it} \leq (n-1) \qquad i = 1, \ldots, n \quad t = 1, 2, \ldots, m \tag{17}$$

$$Y_{ijt} = \{0, 1\}, X_{ijt} = \{0, 1\}, S_{it} \geq 0, In_{it} \geq 0, D_{it} \geq 0, In_{i0} = 0, i, j = 0, \ldots, n \quad t = 1, \ldots, m$$

Based on constraint (5), all input and output of the delivery truck to location *i* on the given day must be zero when all demands at location *i* are zero on the given day.

However, the demand for location *i* can be met either on the same day or the previous days when there is a demand at this location. Constraints (6) and (7) are standard in TSP and ensure that each location is met by a delivery truck only once during the period.

Based on constraint (8), the location must be visited by a delivery truck on the same day if the demand of location i is more than zero. Constraint (9) guarantees that the demand for each roadside assistance car will be met by a delivery truck during the planning period. Constraints (10) and (11) determine the inventory or shortage at the end of each day.

Constraint (12) also shows the balance between shortage and inventory. The amount of inventory beforehand, plus the number of orders received on the same day, should equal the amount of demands minus shortage on the same day.

Constraints (13)–(15) guarantee that output and input to the warehouse must be equal. Furthermore, the delivery truck cannot be sent by the company more than once on the same day when there is a demand for distribution.

Sub-tour deletion constraints were added to the model by equations (16) and (17). Two ways for elimination sub-tour are presented by Eshghi (2019).

The model should be capable of deciding the day the delivery truck meets the demand for specific locations. It also calculated the route that the delivery truck tour should take.

For example, if the model proposes to supply on the first and fourth days, in addition to the orders on the first days, the orders on the second and third days must be sent on the first day since there is no distribution plan on the second and third days. Further, all roadside assistance cars must be visited on distribution days, and the transportation cost is the same for all supply days. Also, their tour is the same because the distances between the regions do not change daily.

Practically, the above model can be divided into two separate models. The first model specifies the tour, and the second model identifies the days when the supply should occur. The first model is a simple TSP or VRP, which must solve, and the optimal calculated cost will be used in the second model as transportation costs.

The first model can be solved by simple integer programming, as reported in Eshghi's (2019) book. This model removes the time-related indices (*t*) since the delivery truck tours are the same on all supply days.

(Model 1)

$$Min\ Z = \sum_{i=0}^{n} \sum_{j=0}^{n} c_{ij} X_{ij} \tag{18}$$

$$\sum_{j \neq i}^{n} X_{ij} = 1 \qquad i = 0, 1, ..., n \tag{19}$$

$$\sum_{i \neq j}^{n} X_{ji} = 1 \qquad j = 0, 1, ..., n \tag{20}$$

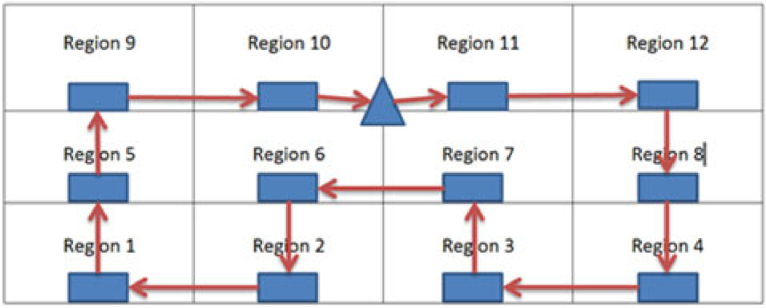
$$u_i - u_j + (n-1)x_{ij} \leq (n-2) \quad i, j = 1, ..., n \tag{21}$$

$$1 \leq u_i \leq (n-1) \qquad i = 1, ..., n \tag{22}$$

$$X_{ijt} = \{0, 1\}, \quad i, j = 0, ..., n \quad t = 1, 2, ..., m$$

Based on the data presented in Figure 1 and Table 2, and by solving the above model, the delivery truck will have the tour, as shown in Figure 2, which costs 5,400 monetary units to the company. This means that when the company distributes spare parts among roadside assistance cars, it must pay 5,400 units of currency per time.

Figure 2 The vehicle tour between the roadside assistance cars gained by solving the TSP model (see online version for colours)



Finding delivery days is modelled by defining some new variables.

$Yn_t = 1$ if orders are distributed on day t; otherwise, zero.

$Y_{tk} = 1$ if the order distribution on day k is done on day t; otherwise, zero.

C the cost of order distribution among customers per day is calculated by solving the first model [equations (18)–(22)] and is equal to 5,400 units.

The objective of the second model is defined as follows.

(Model 2)

$$Min\ Z = \sum_{t=1}^{m} C * Yn_t + \sum_{i=1}^{n}\sum_{t=1}^{m} Ci * In_{it} + \sum_{i=1}^{n}\sum_{t=1}^{m} Cs * S_{it} \quad (23)$$

The constraints of the second model are as follows removing the restrictions related to routing and adding the restrictions related to the determination of distribution days.

$$Y_{tt} + 2 * Y_{kl} \le 2 \qquad k, t, l = 1, 2, ..., m \quad t > 1 \quad k < t \quad l > t \quad (24)$$

$$Y_{tt} = Yn_t \qquad t = 1, 2, ..., m \quad (25)$$

$$Y_{tk} \le Yn_t \qquad k = 1, 2, ..., m \quad t = 1, 2, ..., m \quad k > t \quad (26)$$

$$\sum_{t=1}^{k} y_{kt} = 1 \qquad k = 1, 2, ..., m \quad (27)$$

$$\sum_{k \ge t}^{m} d'_{ik} y_{tk} = D_{it} \qquad i = 1, ..., n \quad t = 1, 2, ..., m \quad (28)$$

$$In_{it} \ge In_{i,t-1} + D_{it} - d_{it} \qquad i = 1, ..., n \quad t = 1, 2, ..., m \quad (29)$$

$$S_{it} \ge d_{it} - In_{i,t-1} - D_{it} \qquad i = 1, ..., n \quad t = 1, 2, ..., m \quad (30)$$

$$D_{it} + In_{i,t-1} - d_{it} + S_{it} = 0 \quad i = 1, ..., n \quad t = 1, 2, ..., m \tag{31}$$

$$Yn_t = \{0, 1\}, Y_{tk} = \{0, 1\}, S_{it} \geq 0, In_{it} \geq 0, D_{it} \geq 0, In_{i0} = 0, i = 1, ..., n, t, k = 1, ..., m$$

Solving the model shown in equations (23)–(31) indicates the optimal number of days that the distribution should take place. Based on this model, the costs are minimised when the distribution occurs on the first, second, and fourth days using the Gams software (https://github.com/fshafaei/GAMS-Code). In this condition, the cost of transportation will be 16,200 monetary units, the inventory cost in the roadside assistance cars will be 15,660 monetary units, and the shortage cost in the five days (assuming the transfer of parts between roadside assistance cars for each region) will be 36,850 monetary units. Thus, the total cost will be 68,710 monetary units.

5 Sensitivity analysis

5.1 Sensitivity analysis on unit costs of transportation, inventory, and shortage

Considering the present parameters and hypotheses, the supplying costs for roadside assistance cars in optimal condition are 68,710 monetary units. Based on the designed model, the distribution on the first day should only cover the orders of the same day, while the distribution on the second day should cover the orders of the second and third days. In addition, the distribution on the fourth day should cover the orders on the fourth and fifth days. The main question is what happens when there is an error in estimating the costs used as a parameter in this model and whether distribution days are still the same as in the proposed model. Therefore, the effective parameters of the distribution costs were analysed in the sensitivity analysis of the answers.

Table 8 The changes in the distribution days in the proposed method by the changes of each cost

Percentage of increase or decrease of parameters	*Parameters*		
	Transportation cost	*Inventory cost*	*Shortage cost*
–100%	1, 2, 3, 4, 5	1	1, 2, 3, 4, 5
–70%	1, 2, 3, 4, 5	1	1, 2, 3, 4, 5
–60%	1, 2, 3, 4, 5	1	1, 2, 3, 4
–50%	1, 2, 3, 4	1, 2	1, 2, 3, 4
–30%	1, 2, 3, 4	1, 2, 4	1, 2, 3, 4
–20%	1, 2, 4	1, 2, 4	1, 2, 4
0%	1, 2, 4	1, 2, 4	1, 2, 4
10%	1, 2, 4	1, 2, 3, 4	1, 2, 4
50%	1, 2, 4	1, 2, 3, 4, 5	1, 2, 4
100%	1, 2, 4	1, 2, 3, 4, 5	1, 2, 4
200%	1, 4	1, 2, 3, 4, 5	1, 2
300%	1, 4	1, 2, 3, 4, 5	1
400%	1	1, 2, 3, 4, 5	1

The present study focused on how the decision variables change when the transportation, inventory, and shortage cost per unit increase or decrease separately while other parameters are constant and calculate the distribution cost through these changes. Table 8 indicates the results of the changes in distribution days by increasing or decreasing transportation, inventory, and shortage cost.

Table 9 shows the total cost when each parameter (transportation, inventory, and shortage cost) decreased or increased, along with the optimal total cost with the available parameters.

Table 9 The changes (amount and percentage) in the distribution cost in the proposed method by changing each parameter.

Percentage of increase or decrease of parameters	*Parameters*					
	Transportation cost		*Inventory cost*		*Shortage cost*	
	Amount (monetary unit)	*Percentage (%)*	*Amount (monetary unit)*	*Percentage (%)*	*Amount (monetary unit)*	*Percentage (%)*
–100.0%	45,460	–33.8%	24,475	–64.4%	28,660	–58.3%
–70.0%	53,560	–22.0%	45,895	–33.2%	41,800	–39.2%
–60.0%	56,260	–18.1%	53,035	–22.8%	45,800	–33.3%
–50.0%	58,490	–14.9%	59,060	–14.0%	49,715	–27.6%
–30.0%	62,810	–8.6%	64,012	–6.8%	57,545	–16.2%
–20.0%	67,090	–2.4%	65,578	–4.6%	61,340	–10.7%
0.0%	68,710	0.0%	68,710	0.0%	68,710	0.0%
10.0%	70,330	2.4%	70,144	2.1%	72,395	5.4%
50.0%	76,810	11.8%	73,290	6.7%	87,135	26.8%
100.0%	84,910	23.6%	74,120	7.9%	105,560	53.6%
200.0%	96,470	40.4%	75,780	10.3%	133,600	94.4%
300.0%	107,270	56.1%	77,440	12.7%	153,100	122.8%
400.0%	117,480	71.0%	79,100	15.1%	172,180	150.6%

As indicated in Table 8, the system decreases the number of distribution days while increasing the transportation and shortage costs. For example, assuming that other costs are constant, it is better to distribute transportation costs every day when a 60% reduction occurs in these costs compared with the current situation. The same situation can happen when the shortage cost decreases by 70%.

However, distributing orders only once on the first day is preferred when the inventory cost decreases by 50% or higher. Contrarily, assuming other parameters are constant, the situation is the opposite while increasing each cost separately. In other words, distribution days decrease if transportation and shortage costs increase and decrease when inventory costs rise.

Based on the results in Table 9, the proposed model is the least sensitive to increasing inventory costs. The total cost increases by 15%, while the inventory cost increases by 400%. However, the model is most sensitive to an increase in shortage costs. For example, increasing 400% in the cost of shortage leads to a 150% increase in the total cost, while a 71% increase occurs in the total cost by increasing the transportation cost by 400%. Therefore, it is recommended to avoid increasing shortage costs as much as possible. As displayed in Figure 3, the shortage, transportation, and inventory costs play the most significant role in the distribution cost, respectively.

Figure 3 The changes in the distribution cost by changing one type of cost and keeping other costs constant in the proposed method (see online version for colours)

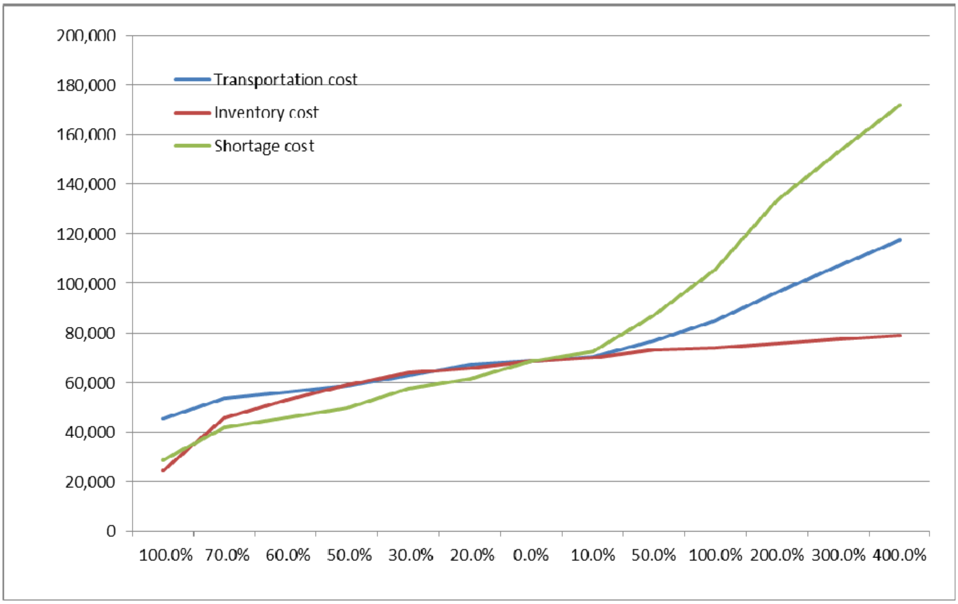


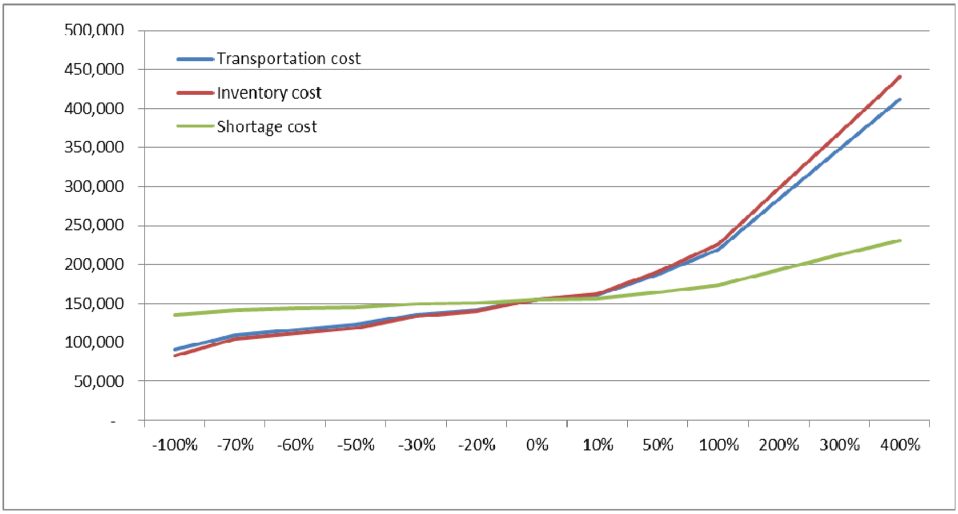
Table 10 The changes (amount and percentage) in the distribution cost in the current method by changing each parameter.

Percentage of increase or decrease of parameters	*Parameter*					
	Transportation cost		*Inventory cost*		*Shortage cost*	
	Amount (monetary unit)	*Percentage (%)*	*Amount (monetary unit)*	*Percentage (%)*	*Amount (monetary unit)*	*Percentage (%)*
–100%	90,475	–41.5%	83,275	–46.2%	135,600	–12.3%
–70%	109,735	–29.1%	104,695	–32.3%	141,323	–8.6%
–60%	116,155	–24.9%	111,835	–27.7%	143,230	–7.4%
–50%	122,575	–20.8%	118,975	–23.1%	145,138	–6.2%
–30%	135,415	–12.5%	133,255	–13.8%	148,953	–3.7%
–20%	141,835	–8.3%	140,395	–9.2%	150,860	–2.5%
0%	154,675	0.0%	154,675	0.0%	154,675	0.0%
10%	161,095	4.2%	161,815	4.6%	156,583	1.2%
50%	186,775	20.8%	190,375	23.1%	164,213	6.2%
100%	218,875	41.5%	226,075	46.2%	173,750	12.3%
200%	283,075	83.0%	297,475	92.3%	192,825	24.7%
300%	347,275	124.5%	368,875	138.5%	211,900	37.0%
400%	411,475	166.0%	440,275	184.6%	230,975	49.3%

It is worth noting that the evaluation of the changes in costs of the current situation reveals different conditions. Table 10 shows the changing status in the total cost of the current distribution method among roadside assistance cars when the transportation, inventory, and shortage costs change.

As shown in Figure 4, each cost influences the total cost of the current method differently. The inventory cost had the highest effect on the total cost, followed by the transportation cost. In addition, the total cost was much more sensitive to the change in transportation and inventory costs, and the lowest sensitivity was related to the shortage cost. Further, less shortage occurs since the current method increases the inventory of roadside assistance cars. Therefore, increasing the shortage has a minor influence on increasing the total costs.

Figure 4 The changes in the distribution cost by changing one type of cost and keeping others constant in the current method (see online version for colours)

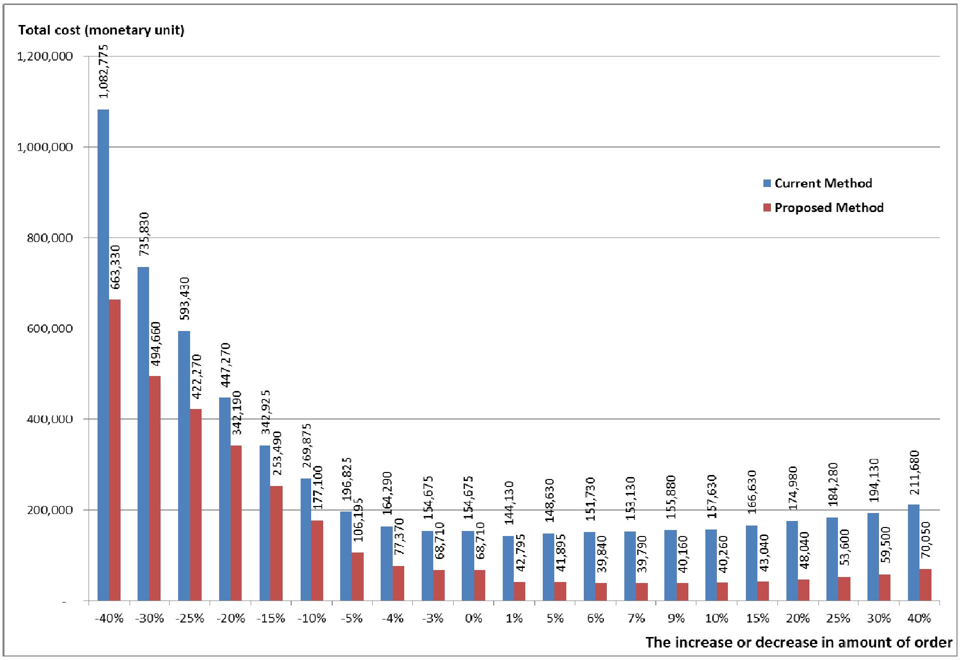


5.2 Sensitivity analysis on order quantity

Another question regarding the distribution of spare parts policy is whether the amount of specified inventory to give to each roadside assistance car changes the distribution plan. Considering the existing conditions, given data, and designed model, changing the distribution plan in this roadside assistance company is essential. However, another question is whether it is better to change the distribution plan while increasing or decreasing the number of daily parts delivered to the roadside assistance cars. For this, we have gradually changed the company's predicted demand from –40% to +40%. Then, the distribution costs were compared in the current situation and the proposed model.

Figure 5 displays an increase or decrease in the total cost of supplying parts in the current and proposed methods. Based on these results, a significant increase occurred in the total supply cost while decreasing order quantity by 40% compared to the present situation. Further, the increase is considerably higher in the current method of distributing parts. Nevertheless, the total cost decreased in both methods until reaching the existing order. However, increasing the number of orders needed for the roadside assistance cars increased after some time.

Figure 5 The distribution cost based on the amount of decrease or increase in the order quantity (see online version for colours)



In the current method, the total cost is minimal when a 1% increase occurs in the number of orders in the existing situation. Assuming that all conditions are stable, it is recommended to increase the number of orders for the parts delivered to each car by about 1% while maintaining the current distribution method. However, as shown in Figures 5–7, more than 101,133 monetary units can reduce costs while occurring the 1% increase in orders in the proposed method, which is about 70% of the distribution cost in the current method.

The minimum cost occurs by increasing the orders by 7% compared with the existing situation where the proposed method is selected for distributing the spare parts (Figure 5). Under these circumstances; the proposed method can reduce the costs of supplying parts by 113,340 units. (74% reduction is observed in the total cost, as shown in Figure 7).

Based on these results, the proposed distribution method can have a significant advantage over the current method, irrespective of the number of orders by the company. Therefore, based on sensitivity analysis, changing the distribution method with any amount of orders specified for each roadside assistance car is necessary. Furthermore, based on the proposed method, the costs can significantly decrease by 23% and 74% in the worst and best conditions.

Figure 6 Amount of reduction in the distribution cost by the proposed method compared with the current method (see online version for colours)

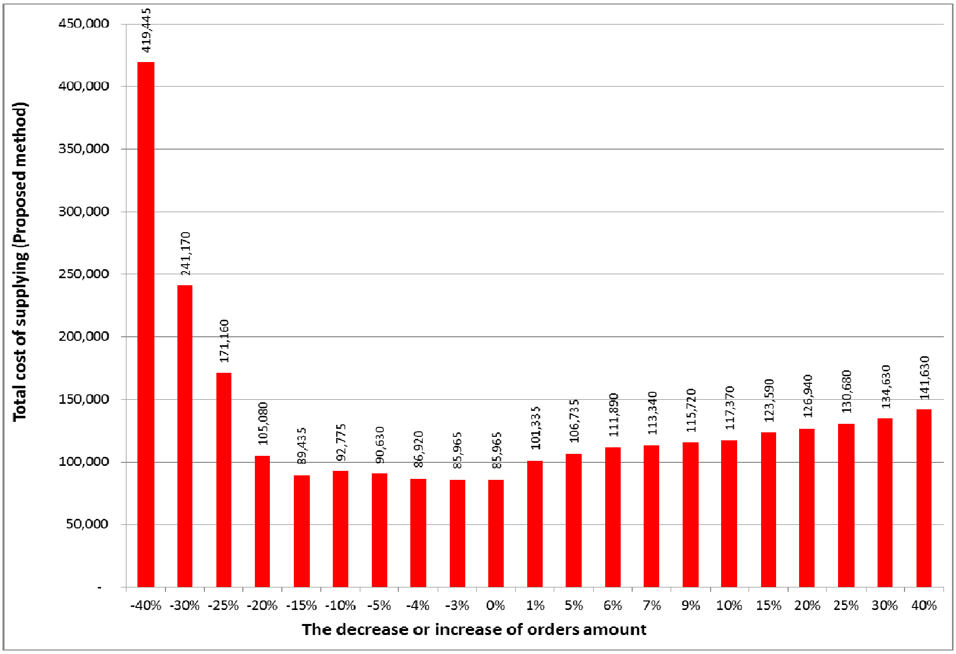
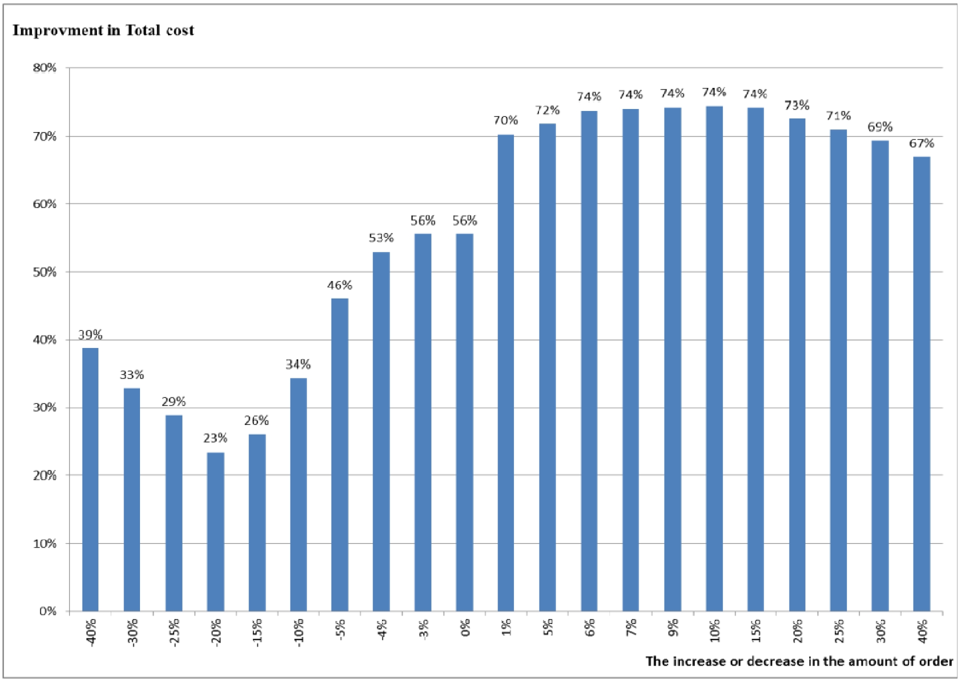


Figure 7 An increase in the percentage of the distribution cost by the proposed method compared with the current method (see online version for colours)



6 Conclusions and suggestions for future works

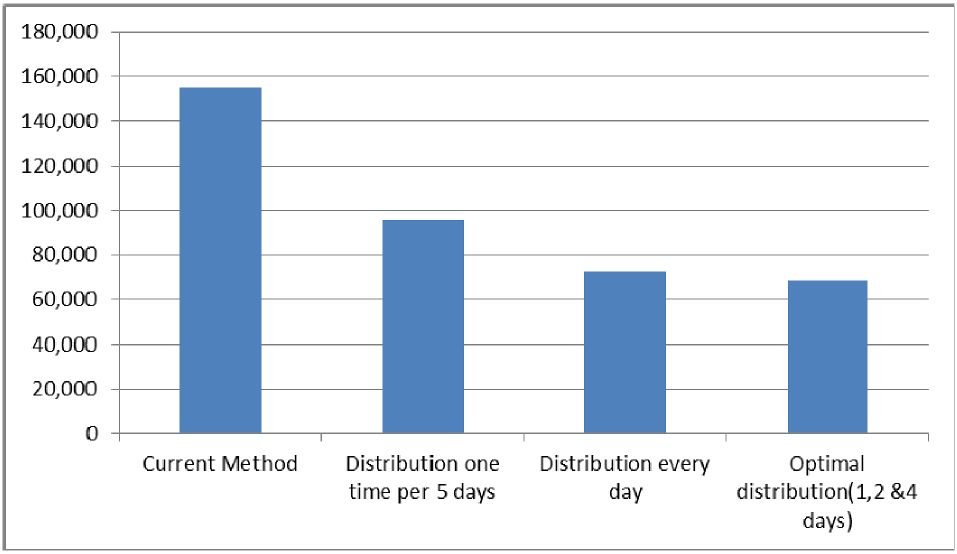
Based on the result presented here, going each roadside assistance car to the warehouse was compared with the situation in which the orders were sent by a delivery truck daily. However, the possibility of transferring the parts between roadside assistance cars in each region was considered. As shown in Table 11, four different distribution plans were compared. In the first row, the cost of the current method was estimated with the possibility of moving the parts between the roadside assistance cars in the same region. In the current method, each car goes to the company's warehouse every five days and picks up the necessary parts for the next 5 days. The current method is considered as a base cost to compare the cost reduction in the proposed methods, indicating the efficiency of the proposed methods.

In the second row, the cost of the method by which the roadside assistance cars do not go to the warehouse was presented, and a delivery truck delivers the parts to the roadside assistance cars once every five days. In this case, only the transportation cost was reduced, and the total cost improved by 38% over the current method (the first row).

Table 11 Comparison of the total cost in different methods of distributing spare parts

	Trans. Co.	*Inv. Co.*	*Short. Co.*	*Total cost*	*Improvement (%)*
Current method	64,200	71,400	19,075	154,675	0%
Distribution one time per 5 days	5,400	71,400	19,750	95,875	38%
Daily distribution	27,000	1,660	43,800	72,460	53%
Optimal distribution (1, 2 and 4 days)	16,200	15,660	36,850	68,710	56%

Figure 8 Comparison of the distribution cost in the different distribution plans (see online version for colours)



On the third row, a delivery truck delivers the parts daily to roadside assistance cars. In this situation, the distribution costs decrease by more than 50% compared to the current method. Finally, the final row is calculated by the proposed method, in which optimal distribution days are extracted based on this model. The model suggests that the parts be delivered on the first, second, and fourth days to the roadside assistance cars. In this case, there is a 56% reduction in the total costs compared with the current method. Figure 8 compares the total costs in each delivery plan using data shown in Table 11.

This study assumed that only one delivery truck visits all roadside assistance cars on the distribution day. However, these assumptions can be removed for future research, and the proposed model will determine which roadside assistance cars must be visited on what distribution day.

One of the side benefits of the proposed method is the reduction of air pollution. For example, Grzesiak and Sulich (2022) presented that each car emitted 191 g/km CO_2 into the air. Therefore, in our presented method, the emitted CO_2 from roadside assistance cars, which is currently 8,951 kg (for 36 cars) each year, will be reduced to 2,259 kg. This 75% of emitted CO_2 reduction is extremely valuable for air pollution, and the impact of the presented method on air pollution can be continued as future research following our study.

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