Improvement of distribution logistics processes using Vehicle routing problem with pickup and delivery with time windows algorithm

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Abstract

Distribution logistics is one of the key areas of logistics. Correct setup of the distribution logistics processes is directly linked to customer service provided and affects the company's economic performance. This article is focused on distribution logistics processes of companies providing express courier services. The market of companies providing express courier services is very competitive. There are many companies offering very similar services. This is one of the reasons why companies need to streamline their processes and as well distribution logistics processes. Express courier companies operate on a very turbulent market where customer requirements change every day. Customers are demanding transportation of various products from different source destinations to various target destinations respecting time windows loading and unloading. The use of the Vehicle routing problem with pickup and delivery with time windows algorithm is one of the ways to improve processes of distribution logistics for express courier companies. The aim of this article was to test the use of the algorithm in terms of real practice. The algorithm was simulated on the real data of the company provides express courier services.
KEY WORDS: *distribution logistics, vehicle routing problem with pickup and delivery with time windows, express courier service provider*

1. Introduction

The issue of distribution logistics improvement is very current especially from the perspective of companies providing express courier services. There are a large number of companies in this market. This makes it a very competitive sector. The express courier services companies must strive to increase the level of the customer service provided with optimum pricing policy. At the same time, it must reduce costs. However, customer demands are increasingly challenging. The issue of distribution logistics is affected by many limitations and influencing factors for example: changing demand every day, seasonal effects, time windows etc.

2. Theoretical background of the distribution logistics and vehicle routing problem algorithms

Importance of distribution logistics has been driven by the increase of population in the cities, the traffic problems and public pressure [1]. Vehicle routing problems which provides the core solutions in distribution and city logistics has recently received attention among researchers and practitioners of transportation and logistics [2, 3]. Vehicle routing problems concern the challenge of selecting a set of routes for a fleet of vehicles to serve the demands of a set of customers [4]. The first authors who introduce the truck dispatching problem were Dantzig and Ramser [3, 5]. The vehicle routing problem was proposed as a generalization of the traveling salesman problem [6]. Then Clarke and Wright generalized this problem to a linear optimization problem that is common in the domain of logistics and transport [7].

Kim et al. [8] described the historical timeline of the vehicle routing research. The basic line of algorithms consists of static vehicle routing problems there are: capacitated vehicle routing problem (in 1959), heterogeneous vehicle routing problem (in 1964), stochastic and multi-depot vehicle routing problem (in 1969), pickup and delivery vehicle routing problem (in 1976), vehicle routing problem with time windows (in 1977), split-delivery vehicle routing problem (in 1989), vehicle routing problem with loading constraints (in 2003) and multi-echelon vehicle routing problem (in 2008). Another line of algorithms consists of dynamic vehicle routing problems there are: dynamic vehicle routing problem (in 1976), capacitated dynamic vehicle routing problem (in 1993), dynamic vehicle routing problem with time windows (in 1995), stochastic dynamic vehicle routing problem (in 2000), pickup and delivery dynamic vehicle routing problem (in 2004) and heterogeneous dynamic vehicle routing problem (in 2007). The newest line of algorithms consists of eco-friendly vehicle routing problems there are: green vehicle routing problem (in 2006), vehicle routing problem with reverse logistics (in 2007) and pollution routing problem (in 2011). [8]

Current vehicle routing problem models are quite different from the models introduced by Dantzig and Ramser [5] and Clarke and Wright [7]. They increasingly aim to incorporate real-life complexities, such as time-dependent travel times (reflecting traffic congestion), time windows for pickup and delivery and input information (for example demand information) that changes dynamically over time [3]. Nowadays vehicle routing problem software is being used by thousands of companies [9, 10]. The aim of this article was to test the use of the vehicle routing problem with pickup and delivery with time windows algorithm in terms of real practice. The algorithm was simulated on the real data of the company provides express courier services.

3. Methods and data

The vehicle routing problem with pickup and delivery with time windows algorithm was used in this case study. Desaulniers et al. [11] described this algorithm and they used these types of variables: binary flow variables x_{ijk}, time variables T_{ik} (specifying when vehicle k starts the service at node $i \in V_k$ and variables L_{ik} giving the load of vehicle k after the service at node $i \in V_k$ has been completed. The formulation of vehicle routing problem with pickup and delivery with time windows according to Desaulniers et al. [11] is as follows formulas 1-15:

$$min \sum_{k \in K} \sum_{(i,j) \in A_k} c_{ijk} x_{ijk} \quad (1)$$

subject to

$$\sum_{k \in K} \sum_{j \in N_k \cup \{d(k)\}} x_{ijk} = 1 \, ; \; \forall \, i \in P \quad (2)$$

$$\sum_{j \in N_k} x_{ijk} - \sum_{j \in N_k} x_{j,n+i,k} = 0 \, ; \; \forall \, k \in K, i \in P_k \quad (3)$$

$$\sum_{j \in P_k \cup \{d(k)\}} x_{o(k),j,k} = 1 \, ; \; \forall \, k \in K \quad (4)$$

$$\sum_{i \in N_k \cup \{o(k)\}} x_{ijk} - \sum_{i \in N_k \cup \{d(k)\}} x_{ijk} = 0 \, ; \; \forall \, k \in K, j \in N_k \quad (5)$$

$$\sum_{i \in D_k \cup \{o(k)\}} x_{i,d(k),k} = 1 \, ; \; \forall \, k \in K \quad (6)$$

$$x_{ijk}\left(T_{ik} + s_i + t_{ijk} - T_{jk}\right) \leq 0; \; \forall \, k \in K, (i,j) \in A_k \quad (7)$$

$$a_i \leq T_{ik} \leq b_i; \; \forall \, k \in K, i \in V_k \quad (8)$$

$$T_{ik} + t_{i,n+i,k} \leq T_{n+i,k}; \; \forall \, k \in K, i \in P_k \quad (9)$$

$$x_{ijk}\left(L_{ik} + l_j - L_{jk}\right) = 0; \; \forall \, k \in K, (i,j) \in A_k \quad (10)$$

$$l_i \leq L_{ik} \leq C_k; \; \forall \, k \in K, i \in P_k \quad (11)$$

$$0 \leq L_{n+i,k} \leq C_k - l_i; \; \forall \, k \in K, n+1 \in D_k \quad (12)$$

$$L_{o(k),k} = 0; \; \forall \, k \in K \quad (13)$$

$$x_{ijk} \geq 0; \; \forall \, k \in K, (i,j) \in A_k \quad (14)$$

$$x_{ijk} binary; \; \forall \, k \in K, (i,j) \in A_k \quad (15)$$

The use of vehicle routing problem with pickup and delivery with time windows algorithm was tested on the real case study which is the method of the qualitative research based on the study of one or a small amount of situations for application of the findings for the similar cases according to Nielsen, Mitchell and Nørreklit [12].

This algorithm was tested in the Microsoft Excel workbook “VRP Spreadsheet Solver” which is an open source platform using Bing Maps [13]. The basic assumptions were as follows: homogenous vehicle types, vehicles must return to the depot, delivery locations don´t have to be visited before pickup locations, internal working time limit for drivers is 12 hours and the maximal total amount of goods distributed in the vehicle is 6 000 kg. The real express courier company and specific dates were selected for this case study. This express courier company has own depot in Pardubice. The case study was processed for 65 customers on 1. 3. 2019. The location of the depot and the location of 65 customers are in the Fig. 1.

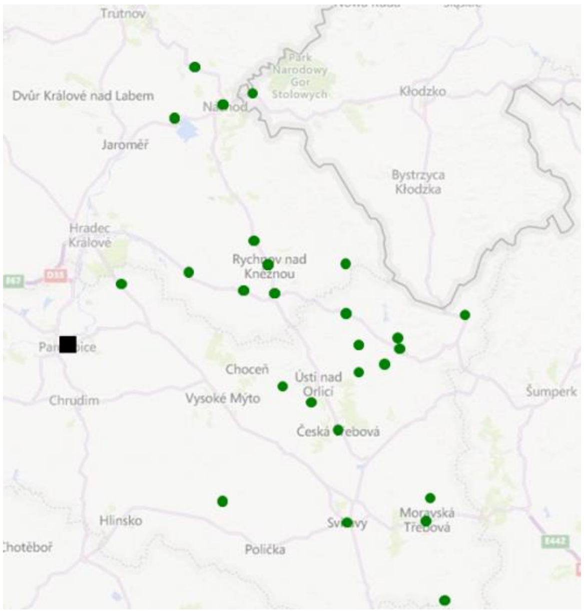

Fig. 1 The location of the depot (Pardubice) and 65 customers [authors based on 13]

The location of the depot and the locations of the customers are presented in the Table 1. The depot located in Pardubice is marked with the number 0. The individual customers have numbers 1-65.

Table 1 Locations, time windows, pickup and delivery amount of the depot and 65 customers [authors]

No.	Location	Time window		Amount		No.	Location	Time window		Amount	
		start	end	pickup [kg]	delivery [kg]			start	end	pickup [kg]	delivery [kg]
0	Pardubice (depot)	04:00	22:00	---	---	33	Žamberk	08:00	16:00	---	372.0
1	Česká Třebová	07:00	14:00	---	100.0	34		08:00	14:00	---	915.0
2	Řetová	08:00	16:00	---	482.0	35	Letohrad	08:00	18:00	---	300.0
3	Jehnědí	08:00	16:00	---	675.0	36		08:00	16:00	---	292.9
4	Vysoké Mýto	08:00	16:00	---	410.0	37	Bystřec	08:00	16:00	---	500.0
5		08:00	16:00	---	395.0	38	Sobkovice	08:00	16:00	---	320.0
6		08:00	16:00	---	360.0	39	Letohrad	07:00	18:00	---	70.0
7	Svitavy	08:00	16:00	---	1243.2	40	Králíky	08:00	16:00	---	10.0
8	Moravská Třebová	08:00	16:00	---	280.0	41	Dolní Dobrouč	08:00	16:00	---	100.0
9	Staré Město u M. T.	13:00	15:00	453.0	---	42	Jablonné n/O	08:00	14:00	---	450.0
10	Jevíčko	08:00	17:00	194.0	---	43	Verměřovice	10:00	20:00	440.0	---
11		10:00	14:00	223.0	---	44		10:00	20:00	2040.0	---
12	Náchod	08:00	16:00	---	164.0	45	Letohrad	07:00	15:00	1.0	---
13		08:00	19:00	---	1286.0	46	Rychnov nad Kněžnou	08:00	16:00	---	120.0
14		08:00	16:00	---	1000.0	47		08:00	16:00	---	258.0
15		08:00	16:00	---	73.0	48		08:00	16:00	---	30.0
16		08:00	16:00	---	265.0	49		08:00	16:00	---	963.6
17		08:00	16:00	---	748.0	50		12:00	14:00	---	474.0
18		08:00	16:00	---	5.0	51		08:00	16:00	---	825.0
19		08:00	16:00	---	133.0	52		08:00	16:00	---	34.0
20		08:00	16:00	---	45.0	53	Solnice	13:00	16:00	---	25.0
21		08:00	16:00	---	269.0	54	Týniště n/O	06:00	14:00	---	315.0
22	Červený Kostelec	08:00	16:00	---	110.0	55	Kostelec n/O	08:00	16:00	---	434.0
23		08:00	16:00	---	421.0	56	Vamberk	08:00	16:00	---	150.0
24		08:00	16:00	---	0.1	57		08:00	16:00	---	5.0
25	Česká Skalice	08:00	16:00	---	268.0	58	Rokytnice v/O	08:00	14:00	---	675.0
26	Kudowa-Zdrój	08:00	16:00	---	15.0	59	Býšť	08:00	16:00	---	7.0
27	Náchod	07:00	13:00	272.0	---	60	Kostelec n/O	09:00	14:00	3000.0	---
28	Červený Kostelec	09:00	14:00	850.0	---	61	Solnice	08:00	17:00	20.0	---
29	Náchod	10:00	13:30	1100.0	---	62	Kostelec n/O	09:00	14:00	43.0	---
30	Červený Kostelec	09:00	17:00	817.0	---	63	Vamberk	06:00	14:00	380.0	---
31	Červený Kostelec	09:00	17:00	84.0	---	64		11:00	14:00	87.0	---
32	Jablonné nad Orlicí	07:00	14:00	---	220.0	65	Kostelec n/O	06:30	14:00	562.0	---

Explanatory notes: No. (Number), M. T. (Moravské Třebové), n/O (nad Orlicí), v/O (v Orlických horách)

All subjects have strictly set the time windows (the start of the time window, the end of the time window) that must be respected. Due to the simultaneous delivery and pickup of goods, weights of goods in kilograms for delivery and pickup are listed. In some cities, more customers must be served, for example Vysoké Mýto, Náchod, Červený Kostelec, Rychnov nad Kněžnou etc.

4. Results and discussion

We tested the use of VRP Spreadsheet Solver in this case study for 1-5 homogenous vehicles and we tried to find the optimal solution in terms of restrictive conditions. Results using VRP Spreadsheet Solver for 1-5 homogeneous vehicles are shown in the Table 2.

Table 2 Results of the case study according to the number of used vehicles [authors based on 13]

Number of used vehicles	Result
1	Unsolvable. All conditions were not met.
2	Unsolvable. All conditions were not met.
3	Solvable. Vehicle driver working time exceeded (for 3rd vehicle).
4	Solvable. All conditions have been met.
5	Solvable. All conditions have been met. Inefficient.

The use of 1-2 vehicles is insufficient, as it is not possible to serve all customers in compliance with the restrictive conditions. The use of 3 vehicles is sufficient, all customers are served, but the driver working time limit (for 3rd vehicle) is exceeded, thus all the constraints are not met. The use of 4 vehicles is already sufficient and optimal in terms of restrictive conditions set, because all customers are served and all limiting conditions are met. The use of 5 vehicles is also possible because all customers are served and all the constraints are met. However, this solution is more expensive, thus inefficient from the perspective of company provides express courier services.

The solution of the case study for 4 vehicles with the individual vehicle routes and served customers is in the Table 3.

Table 3 The solution of the case study with routes and information about amounts [authors based on 13]

Vehicle 1	Wor.	Total	Vehicle 2	Wor.	Total	Vehicle 3	Wor.	Total	Vehicle 4	Wor.	Total
Location	time	am.	Location	time	am.	Location	time	am.	Location	time	am.
Depot	00:00	3 319	Depot	00:00	3 625	Depot	00:00	5 624	Depot	00:00	4 045
C 62	03:15	3 362	C 58	02:15	2 950	C 54	00:55	5 309	C 5	02:15	3 650
C 55	03:30	2 928	C 40	03:14	2 940	C 20	02:15	5 264	C 6	02:30	3 290
C 65	03:45	3 490	C 38	03:54	2 620	C 16	02:30	4 999	C 4	02:45	2 880
C 64	05:15	3 577	C 42	04:15	2 170	C 12	02:45	4 835	C 2	03:40	2 398
C 56	05:30	3 427	C 32	04:30	1 950	C 15	03:00	4 762	C 1	04:09	2 298
C 57	05:45	3 422	C 44	04:52	3 990	C 21	03:15	4 493	C 7	04:50	1 055
C 51	06:10	2 597	C 43	05:07	4 430	C 13	03:30	3 207	C 10	05:36	1 249
C 52	06:25	2 563	C 35	05:33	4 130	C 18	03:45	3 202	C 11	05:51	1 472
C 50	06:40	2 089	C 39	05:48	4 060	C 17	04:00	2 454	C 8	06:33	1 192
C 46	06:55	1 969	C 36	06:03	3 767	C 14	04:15	1 454	C 9	07:15	1 645
C 49	07:10	1 005	C 45	06:18	3 768	C 19	04:30	1 321	C 41	08:18	1 545
C 47	07:25	747	C 34	06:45	2 853	C 29	04:45	2 421	C 3	08:58	870
C 48	07:40	717	C 33	07:00	2 481	C 27	05:00	2 693	Depot	09:54	870
C 53	08:03	692	C 63	07:32	2 861	C 26	05:26	2 678			
C 61	08:18	712	C 60	07:58	5 861	C 24	06:04	2 678			
Depot	09:14	712	Depot	08:48	5 861	C 22	06:19	2 568			
						C 23	06:34	2 147			
						C 25	07:07	1 879			
						C 30	07:22	2 696			
						C 28	07:37	3 546			
						C 31	07:52	3 630			
						C 59	08:57	3 623			
						C 37	09:12	3 123			
						Depot	09:35	3 123			
Explanatory notes: C (customer), Wor. time (driver´s working time [hh:min]), Total am. (the total amount of goods distributed in the vehicle [kg])											

The vehicle 1 started in the depot and served these customers: C 62, C 55, C 65, C 64, C 56, C 57, C 51, C 52, C 50, C 46, C 49, C 47, C 48, C 53 and C 61, then the vehicle 1 returned to the depot. The vehicle 2 started in the depot and served these customers: C 58, C 40, C 38, C 42, C 32, C 44, C 43, C 35, C 39, C 36, C 45, C 34, C 33, C 63 and C 60, then the vehicle 2 returned to the depot. The vehicle 3 started in the depot and served these customers: C 54, C 20, C 16, C 12, C 15, C 21, C 13, C 18, C 17, C 14, C 19, C 29, C 27, C 26, C 24, C 22, C 23, C 25, C 30, C 28, C 31, C 59 and C 37, then the vehicle 3 returned to the depot. The vehicle 4 started in the depot and served these customers: C 5, C 6, C 4, C 2, C 1, C 7, C 10, C 11, C 8, C 9, C 41 and C 3, then the vehicle 4 returned to the depot.
The results of the case study for four vehicles are presented in the Table 4.

Table 4 Results of the case study for four vehicles [authors based on 13]

Vehicle no.	1	2	3	4
Number of served customers [-]	15	15	23	12
Total distance travelled [km]	104.46	202.87	163.17	261.47
Total working time [hh:min]	09:14	08:48	09:35	09:54
Time window conditions [-]	Fulfilled	Fulfilled	Fulfilled	Fulfilled
Drivers working time conditions [-]	Fulfilled	Fulfilled	Fulfilled	Fulfilled
All customers were served [-]	Fulfilled	Fulfilled	Fulfilled	Fulfilled

Most customers served the vehicle 3 (a total of 23 customers). Other vehicles served approximately the same number of customers (vehicle 1 and 2 – 15 customers and vehicle 4 – 12 customers). In total, all 65 customers were served. Vehicle 4 traveled the greatest distance (261.47 km). Other vehicles traveled between 104.46 and 202.87 km. The total distance traveled by all vehicles was 731.97 km. The internal working time limit for drivers was fulfilled, because in all cases, the total working limit did not exceed 12 hours. The total working time was between 8 and 10 hours (vehicle 1 – 09:14, vehicle 2 – 08:48, vehicle 3 – 09:35, vehicle 4 – 09:54). All restrictive conditions were met when addressing this case study and using 4 vehicles.

The visualization of the case study solution is presented in the Fig. 2. The vehicle 1 is represented by a red curve, the vehicle 2 is represented by a green curve, the vehicle 3 is represented by a purple curve and the last vehicle 4 is represented by a blue curve.

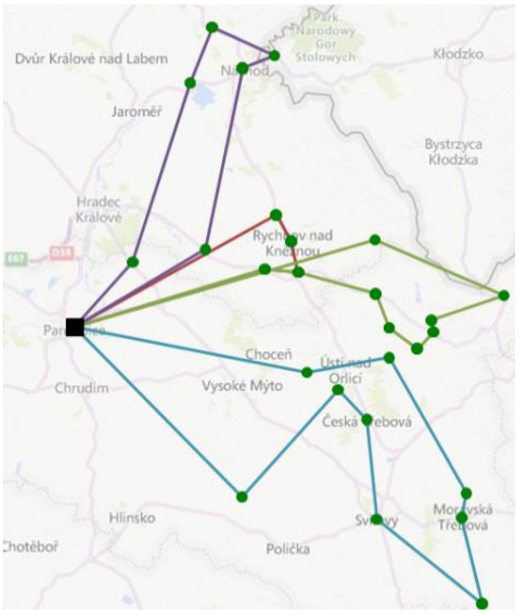

Fig. 2 The visualization of the case study solution [authors based on 13]

The vehicle 3 represented by a purple curve served the north area of the depot. The vehicle 3 served these locations: Náchod (12 customers), Červený Kostelec (6 customers), Česká Skalice, Kudowa-Zdrój, Bystřec, Týniště nad Orlicí and Býšť. The vehicle 1 represented by a red curve served the northeast area of the depot. The vehicle 1 served these locations: Rychnov nad Kněžnou (7 customers), Vamberk (3 customers), Kostelec nad Orlicí (3 customers) and Solnice (2 customers). The vehicle 2 represented by a green curve served the east area of the depot. The vehicle 2 served these locations: Žamberk (2 customers), Letohrad (2 customers), Verměřovice (2 customers), Letohrad (2 customers), Jablonné nad Orlicí, Sobkovice, Králíky, Jablonné nad Orlicí, Rokytnice v Orlických horách, Kostelec nad Orlicí and Vamberk. The vehicle 4 represented by a blue curve served the southeast area of the depot. The vehicle 4 served these locations: Vysoké Mýto (3 customers), Jevíčko (2 customers), Česká Třebová, Řetová, Jehnědí, Svitavy, Moravská Třebová, Staré Město u Moravské Třebové and Dolní Dobrouč.

5. Conclusions

The issue of distribution logistics improvement is very current especially from the perspective of companies providing express courier services. Improving the management and planning of distribution logistics affects related distribution costs and the customer service level. Companies should use the most modern software tools and algorithms to manage and plan distribution logistics processes. This topic is strongly linked with the city logistics issue too, because distribution logistics has direct impact on the traffic flow in the cities and in the whole agglomerations including environmental impacts and society impacts as a whole.

The aim of this article was to test the use of the vehicle routing problem with pickup and delivery with time windows algorithm in terms of real practice. The algorithm was simulated on the real data of the company provides express courier services. The tool “VRP Spreadsheet Solver” was used to process a case study. The use of this tool and vehicle routing problem with pickup and delivery with time windows algorithm for 65 customers was tested. The number of 1-5 homogeneous vehicles was simulated. The routes proposed by the “VRP Spreadsheet Solver” tool were better in terms of total distance travelled and total working time compared to the routes proposed by the company. At the same time, the proposed routes have lower costs compared to the routes proposed by the company.

Furthermore, it should be noted that this tool does not foresee any extraordinary events and real-life complexities (traffic congestion, accidents and dynamic changes of information about time windows for pickup and delivery and demand). Simultaneously, the use of this tool and algorithm can improve distribution logistics processes.

Acknowledgment

This paper is published within the solution of the scientific research project of the University of Pardubice no. SGS_2019_010. The authors are grateful for their support.

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