Logistic Planning Tool for Perishable Goods in Accordance with Green Distribution Logistics and Green Reverse Logistics

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Abstract

Distribution and reverse logistics processes are becoming extremely important for companies today. The aim is to reduce continuously the delivery time of goods to buyers or customers while maintaining a set level of customer service. Perishable goods are a special category of goods with a very limited shelf life. This type of goods is very sensitive to temperature fluctuations and any problems in the distribution logistics of perishable goods can lead to their un-saleability in extreme cases. Distribution and reverse logistics processes have an important link to the pillars of sustainability. From the perspective of the social pillar, these logistic activities ensure supply and reverse transport that is important for the functioning of modern human society. From an economic perspective, these logistic processes generate significant costs for companies. From an environmental perspective, distribution and reverse logistics processes generate negative environmental impacts (emissions, noise, and vibration). The aim of the manuscript is to present a vehicle routing problem with pickup and delivery with time windows algorithm-based tool to support logistic planning in the context of distribution and reverse logistics processes and to illustrate its use in a real case study. The use of this tool has led to a reduction in greenhouse gas emissions and cost savings in distribution and reverse logistics for a particular perishable's distribution company.
KEY WORDS: *green logistics; distribution logistics; city logistics; vehicle routing problem with pickup and delivery with time windows; sustainability*

1. Introduction

The logistics of perishable food goods is a major challenge for all chains in the relevant logistics chain, not only in terms of logistics activities. The characteristics of perishable goods affect most logistics activities such as demand forecasting, purchasing, supply, packaging, storage, transport, logistics communication, customer service etc. All logistics activities add value to the customer and are essential. On the other hand, logistics activities also generate negative environmental and social impacts. Companies' efforts towards sustainable logistics activities are also reflected in green practices in distribution and reverse logistics, which is indispensable in the perishable logistics chain. Green distribution logistics and green reverse logistics is therefore a current topic in the perishable's logistics chain.

2. Theoretical Background

The perishable food industry contributes significantly to the economy and society of many developing and developed countries of the world [1]. The perishable food products are characterized by a shorter shelf life and complex and lengthy supply chains [2]. Greening perishable food logistics activities has become an issue of interest to limit the production of greenhouse gas emissions [3]. Perishable goods are goods that are easily rotting, decomposing, and damaged during the distribution logistics processes [4]. The distribution logistics of perishable goods is clearly more complex than that of traditional goods because of uncertainty in all aspects of demand and distribution [5]. This fact is also confirmed for the case of reverse logistics of perishable food [6].

The authors divide the vehicle routing problems into static, dynamic, and eco-friendly [7]. Static vehicle routing problems (hereinafter VRP) include: capacitated VRP, heterogenous VRP, stochastic VRP, multi-depot VRP, pickup and delivery VRP, VRP with time windows, split-delivery VRP, VRP with loading constraints, and multi-echelon VRP; dynamic VRP include: capacitated dynamic VRP, dynamic VRP with time windows, stochastic dynamic VRP, pickup and delivery dynamic VRP, and heterogenous dynamic VRP; eco-friendly VRP include: VRP with reverse logistics, and pollution routing problem [7]. It is evident that the issue of VRP is still very topical. This is evidenced by the large number of research articles in this area, for example [8-10].

The aim of the manuscript is to present a vehicle routing problem with pickup and delivery with time windows algorithm-based tool to support logistic planning in the context of distribution and reverse logistics processes and to illustrate its use in a real case study.

3. Methods and Data

The processing procedure was as follows. In the first step, the existing delivery and collection routes were obtained from the T-Cars software and were analysed. Subsequently, a random standard day was selected; customer´s (store´s) requirements for distribution logistics (delivery), customer´s (store´s) requirements for reverse logistics (collection), exact locations, and time windows of customers were analysed. This data was imported into the VRP Spreadsheet Solver. Subsequently, new distribution and reverse logistics routes were modelled for a randomly selected standard day. Finally, the results of the new routes were compared with the original routes and savings in individual parameters were analysed. The Microsoft Excel workbook "VRP Spreadsheet Solver" is an open-source unified platform for solving and visualizing the results of Vehicle Routing Problems and this platform uses public Geographical Information Systems (Bing Maps) and metaheuristics [11]. There are many studies focusing on the issue of vehicle routing problems addressed by the author of the workbook "VRP Spreadsheet Solver" [12-25]. VRP Spreadsheet Solver uses an algorithm of heuristic method for Vehicle routing problem with pickup and delivery with time windows according to [26] and presented in formulas 1-15. It uses 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 [26].

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

subject to

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

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

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

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

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

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

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

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

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

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

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

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

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

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

In terms of scientific methods, analysis, comparative analysis, and interpretive case study were used in this manuscript. The method of comparative analysis is a data analysis technique for determining which logical conclusions a data set supports [27]. This method was used to compare the original and newly proposed distribution and reverse logistics routes in terms of basic indicators. The interpretative case study is very suitable for exploratory research [28]. The interpretative case study approach minimizes the distance between the explorer and the key decision-maker [29]. The fundamental decisions within the interpretive case studies lie in previous theories, the unit(s) of analysis, the number and selection of cases, the techniques of data collection, and the method(s) by which the collected data will be analysed [30]. The interpretive case study method was used throughout the manuscript when the application of the "VRP Spreadsheet Solver" workbook to the distribution and reverse logistics routes of a specific company focused on perishable food products is illustrated.

4. Results

The company deals with the delivery of perishable food goods to stores and the removal of reverse logistics objects (especially pallets, shipping boxes, etc.) from stores. Distribution logistics is limited by the time windows of individual customers (stores). This is therefore a typical vehicle routing problem with pickup and delivery with time windows task. The company is based in Hodonín (South Moravia). Geographically, the company covers these four regions: Slovakia, North Moravia, East Moravia, and West Moravia. Each region is generally served by two or three vehicles and routes. Table 1 presents original routes by average number of customers, service time, and transport distance within a randomly selected standard day. This data was obtained from the T-Cars software.

Table 1 Original routes by average number of customers, service time, and transport distance [authors, T-Cars software]

Region	Route	Average number of customers [-]	Average service time [hours]	Average transport distance [km]
Slovakia	A	32	7:15	256
	B	33	7:20	235
North Moravia	C	24	7:10	236
	D	26	5:45	136
	E	25	6:30	119
East Moravia	F	30	8:00	192
	G	32	6:15	111
	H	09	4:35	166
West Moravia	I	26	7:50	270
	J	27	8:10	291
	Total	264	68:50	2012

The region of Slovakia and the region of West Moravia was served by two routes (A, B, I, J), while the region of North and East Moravia was served by three routes (C, D, E, F, G, H). Thus, a total of 10 distribution and reverse logistics routes were implemented, and 264 customers (stores) in total were served. The average service time on the route's ranges from 4 hours and 35 minutes (route H) to 8 hours and 10 minutes (route J). The total service time for all routes is 68 hours and 50 minutes. In terms of transport distance, the shortest route is route G (111 km), and the longest route is route J (291 km). The total transport distance of all routes was 2 012 km, and they are always round trips that start and end in Hodonín.

Subsequently, customer´s (store´s) specific requirements for distribution logistics (delivery), customer´s (store´s) specific requirements for reverse logistics (collection), exact locations, and time windows of customers were imported into the VRP Spreadsheet Solver. Furthermore, new distribution and reverse logistics routes were modelled for all original routes. An example of the original route F (obtained from the T-Cars software) and the newly designed route F (exported from the VRP Spreadsheet Solver) is shown in Figures 1 and 2. Figure 2 visualises the routes only as the crow flies, but the transport distance is calculated using roads.

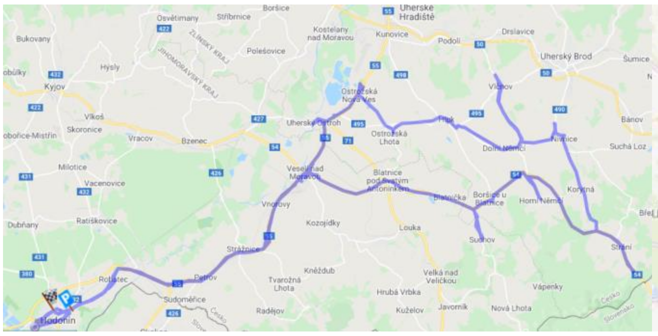

Fig. 1 Route F – original version (T-Cars software)

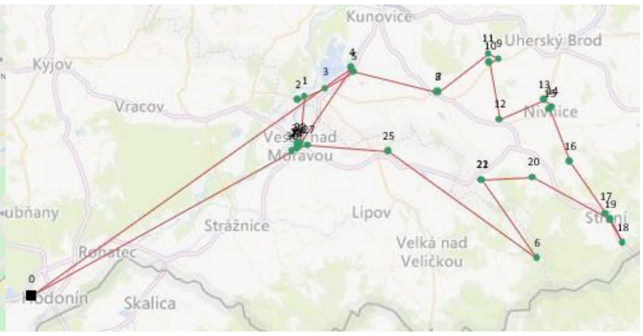

Fig. 2 Route F – proposed version (VRP Spreadsheet Solver)

The specific plan for the proposed version of Route F is shown in Table 2. Table 2 shows the exact order of customers (C 1 – C 30) on the route. The starting point of the route and the destination of the route is the depot in Hodonín. For each customer (store), the exact geographical coordinates (latitude x, y) are presented, which have been imported into a VRP Spreadsheet Solver using Bing maps.

Table 2 Plan of the proposed version of route F according to individual customers [authors, VRP Spreadsheet Solver]

Loc.	Latitude [y]	Latitude [x]	Distance [km]	Loc.	Latitude [y]	Latitude [x]	Distance [km]	Loc.	Latitude [y]	Latitude [x]	Distance [km]
Dep.	48,8493900	17,1041600	00.00	C 70	48,9876500	17,5281800	66.32	C 19	48,9007800	17,7074300	101.96
C 40	49,0047500	17,4382600	36.86	C 11	49,0141000	17,5796800	72.10	C 20	48,9296265	17,6272373	112.89
C 23	48,9535600	17,3841900	44.69	C 90	49,0084610	17,5821590	73.29	C 22	48,9283295	17,5738907	120.30
C 26	48,9529500	17,3815100	44.92	C 10	49,0109100	17,5913400	74.19	C 21	48,9283295	17,5738907	120.30
C 28	48,9491500	17,3801100	45.66	C 12	48,9692500	17,5922900	80.23	C 60	48,8749100	17,6310600	132.95
C 24	48,9508000	17,3828700	46.17	C 13	48,9827200	17,6383400	84.68	C 25	48,9471700	17,4762500	149.86
C 10	48,9848500	17,3888600	51.79	C 14	48,9779800	17,6469500	85.72	C 27	48,9517000	17,3931100	157.31
C 20	48,9825800	17,3821100	52.39	C 15	48,9763031	17,6443329	86.07	C 29	48,9501000	17,3802400	158.82
C 30	48,9909100	17,4103900	55.13	C 16	48,9406900	17,6653700	90.55	C 30	48,9471500	17,3755000	159.61
C 50	49,0016500	17,4401300	58.36	C 17	48,9058100	17,7026900	97.08	Dep.	48,8493900	17,1041600	188.00
C 80	48,9878300	17,5276300	66.21	C 18	48,8854800	17,7202900	99.84				
Notes: Loc. = Location, Dep. = Depot, C = Customer (store)											

Finally, all routes modelled and proposed by the VRP Spreadsheet Solver using the comparative analysis method were compared with the original routes. The result of the comparison between the original and proposed routes is shown in Table 3.

Table 3 Comparison of original and proposed routes [authors]

Region	Route	Service time			Transport distance			Fuel
		Current [hours]	Proposed [hours]	Savings [hours]	Current [km]	Proposed [km]	Savings [km]	Savings [l]
Slovakia	A	7:15	4:30	-2:45	256	206	-50	-10.1
	B	7:20	5:12	-2:08	235	213	-22	-4.8
North Moravia	C	7:10	5:27	-1:43	236	219	-17	-1.5
	D	5:45	5:30	-0:15	136	126	-10	-1.0
	E	6:30	5:27	-1:03	119	118	-1	-0.0
East Moravia	F	8:00	5:25	-2:35	192	188	-4	-0.1
	G	6:15	4:01	-2:14	111	99	-12	-0.4
	H	4:35	3:59	-0:36	166	159	-7	-0.2
West Moravia	I	7:50	6:55	-0:55	270	246	-24	-5.0
	J	8:10	7:05	-1:05	291	268	-23	-4.9
	Total	68:50	53:31	-15:19	2012	1842	-170	-28.0

Three main parameters were compared, namely service time (hours), transport distance (kilometres) and fuel consumption (litres). On each analysed route (A – J), savings were always generated in all monitored parameters. The indicators are partially interlinked with each other. In terms of service time, the greatest savings were recorded on route A (savings of 2:45 hours). The original service time on all routes was 68:50 hours. The newly proposed service time on all routes is 53:31 hours, it is a time saving of 15:19 hours per day. Of course, this time saving is also linked to an economic saving, as there may be a reduction in personal costs for the vehicle drivers.

In terms of transport distance, the greatest savings were also recorded on route A (50 km savings). The original total transport distance on all routes was 2 012 km. The new proposed total distance on all routes is 1 842 km, it is a saving of 170 km per day. This saving is of course linked to economic savings, as fuel costs will be reduced; environmental savings, as lower greenhouse gas emissions will be produced, and the depreciation of the company's fleet will be reduced.

Table 4 presents calculation of fuel cost savings per day, week, and year. Table 4 shows that the daily fuel saving on all routes is 28 litres. On a weekly basis, the fuel saving is approximately 140 litres (assuming a week of 5 working days when the routes are implemented). Over a year, the fuel saving is about 7 280 litres (we assume that a year has 52 weeks when the routes are implemented).

The economic evaluation focuses only on fuel savings although other savings are generated in this area. We assume a diesel price of 1.92 € / litre of fuel. The daily fuel saving is approx. 53 €, the weekly saving is approx. 268 € and the annual fuel saving on all routes is 13 978 €, which is not negligible. As already mentioned, the proposed solution may also generate further savings in the economic area (reduction of wage costs for drivers) and environmental benefits (reduction of greenhouse gas emissions, noise, and vibration).

Table 4 Calculation of fuel cost savings per day, week, and year [authors]

Region	Route	Fuel savings			Cost savings		
		Per day [l]	Per week [l]	Per year [l]	Per day [€]	Per week [€]	Per year [€]
Slovakia	A	-10.1	-50.500	-2 626.00	-19.392	-96.960	-5 041.92
	B	-4.8	-24.000	-1 248.00	-9.216	-46.080	-2 396.16
North Moravia	C	-1.5	-7.500	-390.00	-2.880	-14.400	-748.80
	D	-1.0	-5.000	-260.00	-1.920	-9.600	-499.20
	E	-0.0	-0.005	-0.26	-0.001	-0.009	-0.49
East Moravia	F	-0.1	-0.500	-26.00	-0.192	-0.960	-49.92
	G	-0.4	-2.000	-104.00	-0.768	-3.840	-199.68
	H	-0.2	-1.000	-52.00	-0.384	-1.920	-99.84
West Moravia	I	-5.0	-25.000	-1 300.00	-9.600	-48.000	-2 496.00
	J	-4.9	-24.500	-1 274.00	-9.408	-47.040	-2 446.08
Total		-28.0	-140.005	-7 280.26	-53.761	-268.809	-13 978.09
Notes: week = assumption of 5 working days, year = assumption of 52 weeks, price of fuel (diesel) = 1.92 € / l							

5. Conclusion

The issue of logistics planning in the context of distribution and reverse logistics is a very complex matter and a challenge for many companies. In the food industry, especially for perishable goods, it is a challenging task that can have an impact on the entire supply chain.

The aim of the manuscript was to present a vehicle routing problem with pickup and delivery with time windows algorithm-based tool to support logistic planning in the context of distribution and reverse logistics processes and to illustrate its use in a real case study. The use of logistics planning tools in distribution and reverse logistics is an absolute necessity in today's dynamic and turbulent times, as it helps companies to streamline processes, reduce costs and increase competitiveness. One of the logistics planning tools for distribution and reverse logistics processes is VRP Spreadsheet Solver. This tool allows to solve vehicle routing problem with pickup and delivery with time windows. Using the scientific method of comparative analysis and an interpretive case study, this manuscript illustrated the use of this tool for logistics planning with the comparison of standard routes that the analysed company usually uses. The conclusions of the study are that the use of this tool to support logistics planning can bring economic, personnel, as well as social and environmental benefits to the company. A limitation of this manuscript is that only one company's routes were analysed, but this is standard practice for an interpretive case study. At the same time, it can be assumed that savings would be generated for other routes and companies using this tool. Another limitation is the fact that the tool does not consider the current traffic situation and does not allow dynamic real-time replanning. However, these facts may be the subject of further research.

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