SUSTAINABLE DISTRIBUTION LOGISTICS OF RETAIL CHAINS

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Abstract: Distribution logistics of retail chains is very specific, because the network of retail chains is usually very extensive and there are many constraints for distribution of goods, for example time windows of central warehouses (depots) and stores for loading and unloading, more deliveries within the same day to stores or distribution of objects of reverse logistics from stores to central warehouses. There are many flows between stores and central warehouses, for example product flows, information flows, financial flows, reverse flows etc. Sustainable distribution logistics should respect three pillars of sustainability, there are: economic, social and environmental pillars. Sustainable distribution logistics of retail chains should investigate the possibilities of streamlining with consideration to the pillars of sustainability. The article will focus on the distribution planning tools which are being used for planning of distribution logistics for retail chains. There are some algorithms of graph theory, for example: Vehicle routing problem with pickup and delivery with time windows. The aim of the article will be to find an algorithm for this type of exercise which will respect all defined constraints and pillars of sustainability for distribution logistics of retail chains. The algorithm will be simulated on a specific network of retail chain as a case study.

Keywords: distribution logistics, retail chain, vehicle routing problem, sustainability.

1. Introduction

The popularity of retail chains has grown in recent years among customers. Many retail chains have hundreds of stores and many central warehouses (depots). Demands on transport infrastructure and transport system as a whole are increasing. The intensity of traffic grows in the surroundings of individual stores, not only thanks to customers but also through the distribution logistics. The same applies for the surroundings of the central warehouses (depots) because hundreds of suppliers supply every day central warehouses and central warehouses deliver goods every day to hundreds of stores. It is also widely known that transport and distribution have a negative impact on the environment. This makes it necessary to pay maximum attention to distribution logistics. At the same time, greater emphasis is placed on sustainability issues through three pillars of sustainability and especially on the negative impacts of transport and distribution on the environment from the perspective of the environmental pillar of sustainability.

2. Theoretical Background of the Sustainable Distribution Logistics

Sustainable logistics is a research area developed since the 1990s according to Wiederkehr et al. (2004). Davis and Barekat (2002) stressed the terms like eco-logistics because these terms were increasingly used to define a sustainable environmental logistics. Schulte (1999) described sustainable distribution or sustainable distribution logistics as any means of transportation of goods in logistic chain with lowest possible impact on the environment and society. The term distribution includes according to the author the whole distribution process from storage, order processing and picking, packaging, improved vehicle loadings, delivery to the customer and reverse logistics. Sustainable distribution is based on three pillars: environmental pillar, economic pillar and social pillar. Faccio and Gamberi (2015) perceive logistic activities as the necessary condition for the harmonious growth of every urban area, even if they are also the main cause of pollution, noise and accidents. The rapid development of the demand for urban transportation has a negative impact on urban surroundings and on the environment (Wang et al., 2014). Faccio and Gamberi (2015) defined four groups of key players in the field of distribution logistics there are: retailers (stores etc.), carriers and warehouse companies, residents (inhabitants) and administrators (at national, regional and local levels). Karakikes and Nathanail (2017) stressed the importance of the urban distribution of goods because it is the main component of sustainable transport networks and one of the main contributors on traffic congestion and environmental pollution in the cities and agglomerations. Matsumoto et al. (2017) mentioned sustainable distribution or sustainable distribution logistics which considers both facility for distribution supply chain and also the transportation. Authors further emphasized the associated negative environmental impacts of distribution logistics and the need to use quality planning tools for distribution logistics. New challenges have been observed in models of vehicle routing problems which considered basic tools for implementing sustainable distribution channels in urban areas (Carrabs, Cerulli and Sciomachen, 2014).
Retail chains have usually a very extensive network which consists of depots (central warehouses) $D_1 \cdots D_n$ and customers (stores) $C_1 \cdots C_n$. The stores are supplied directly from direct suppliers $SD_1 \cdots SD_n$ or indirectly from depots. The depots are supplied from indirect suppliers $SI_1 \cdots SI_n$. Direct flows of the goods and indirect flows of the goods are depicted in the Fig. 1. Stores produce reverse flow especially transport units (pallets, crates, boxes etc.). These transport units are returned directly to the direct suppliers or indirectly to the indirect suppliers through the depots. The diagram of the distribution and reverse logistics of retail chains are depicted in the Fig. 1.

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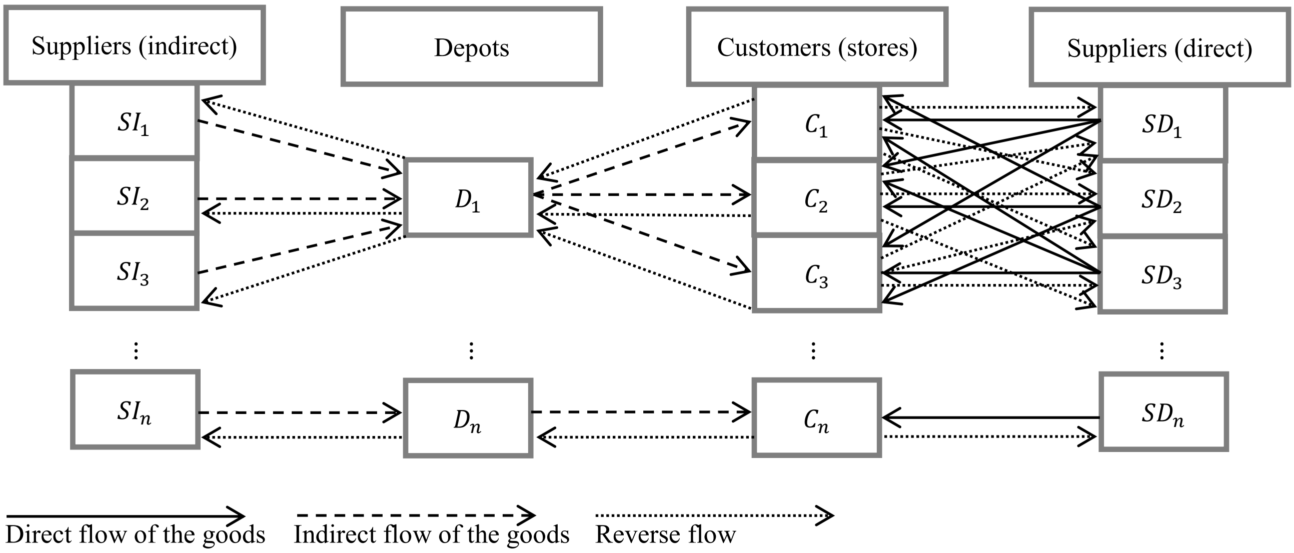

Fig. 1.
The Diagram of the Distribution and Reverse Logistics of Retail Chains
Source: authors

3. Methods and Data

Methods and data are presented in this chapter. The algorithm of heuristic method for Vehicle routing problem with pickup and delivery with time windows is presented firstly. Then VRP Spreadsheet Solver is paid attention because this Microsoft Excel Workbook is used to solve a case study which is theoretically described at the end of the chapter.
Algorithm of heuristic method for Vehicle routing problem with pickup and delivery with time windows according to Desaulniers *et al.* (2002) 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. The formulation of Vehicle routing problem with pickup and delivery with time windows according to Desaulniers *et al.* (2002) is as follows formulas 1-15.

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

subject to

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The linear objective function (1) minimizes the total travel cost. Constraints (2-3) impose that each request is served exactly once and by the same vehicle. Constraints (4-6) characterize a multi-commodity flow structure and ensure that each vehicle k starts from its origin depot $o(k)$ and terminates its route at its destination depot $d(k)$. Compatibility requirements between routes and schedules are handled by constraints (7) and (8) are the time window constraints. For each request, constraints (9) force the vehicle to visit the pickup node before the delivery node. Constraints (10) express the compatibility requirements between routes and vehicle loads, while (11-12) the vehicle dependent capacity intervals at pickup and delivery nodes. The initial vehicle load is imposed by (13), and no negativity and binary requirements are given by (14-15). Constraint sets (3) through (15), as well as the objective function, are separable for each vehicle $k \in K$ (Desaulniers *et al.,* 2002).

The algorithm for Vehicle routing problem with pickup and delivery with time windows is solved in the Microsoft Excel workbook "VRP Spreadsheet Solver" which is an open source unified platform for representing, solving and visualizing the results of Vehicle Routing Problems. VRP Spreadsheet Solver uses public Geographical Information Systems (Bing Maps) and metaheuristics. The author of the "VRP Spreadsheet Solver" is Güneş Erdoğan and its scientific area covers exact and heuristic optimization methods, ambulance location problems, traveling salesman problems, vehicle routing problems and scheduling problems (Güneş, 2018).

Güneş Erdoğan and other co-authors are the authors of the following scientific articles, for example A Note on a Polynomial Time Solvable Case of the Quadratic Assignment Problem (Güneş and Tansel, 2006), A Branch-and-Cut Algorithm for Quadratic Assignment Problems Based on Linearizations (Güneş and Tansel, 2007), Ambulance Location for Maximum Survival (Erkut, Ingolfsson and Güneş, 2008), Computational Comparison of Five Maximal Covering Models for Locating Ambulances (Erkut *et al.,* 2009), The Traveling Salesman Problem with Pickup and Delivery and First-In-First-Out Loading (Güneş, Cordeau and Laporte, 2009), Scheduling Ambulance Crews for Maximum Coverage (Güneş *et al.,* 2010), The Attractive Traveling Salesman Problem (Güneş, Cordeau and Laporte, 2010), The Traveling Salesman Problem with Pickups, Deliveries and Handling Costs (Battarra *et al.,* 2010), A Branch-and-Cut Algorithm for the Non-Preemptive Capacitated Swapping Problem (Güneş, Cordeau and Laporte, 2010), Formulations and Branch-and-Cut Algorithms for the Generalized Vehicle Routing Problem (Bektaş, Güneş and Ropke, 2011), Modelling and solving an m-location, n-courier, priority-based planning problem on a network (Güneş, Tansel and Akgün, 2012), Metaheuristics for the traveling salesman problem with pickups, deliveries and handling costs (Güneş et al., 2012), The Orienteering Problem with Variable Profits (Güneş and Laporte, 2013) and Exact Algorithms for the Clustered Vehicle Routing Problem (Battarra, Güneş and Vigo, 2014).

The case study will be used for application of Vehicle routing problem with pickup and delivery with time windows in the real retail chain. The case study 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 (2015).

The case study data represent the data of the real retail chain in the Czech Republic, but this case study is limited to just one depot (central warehouse) which is located in the Praha-východ and the case study is limited for the one round of distribution within the day. The visualization of the depot and customers (stores) is in the Fig. 2.

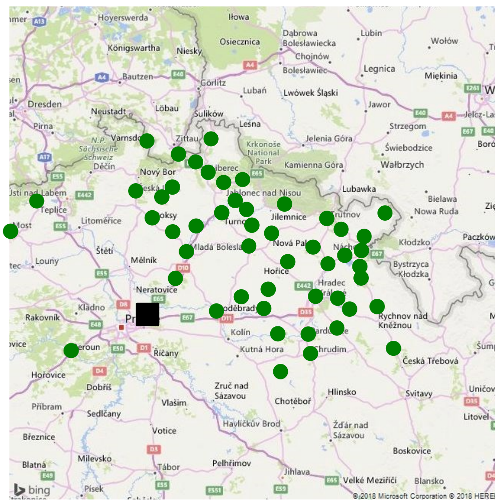

Fig. 2.
The Visualization of the Depot and Customers (Stores)
Source: authors with use Güneş (2018)

Location of the depot, locations of all 50 customers (stores), latitudes, information about start and end of time windows which must be respected, number of pallet space for pickup and delivery (one pallet space represented one standardized euro pallet) are in the Table 1.

Table 1

Locations, Latitudes and Time Windows of the Depot and Customers 01 – 50

Location	Type (depot / customer)	Latitude (y)	Latitude (x)	Time window		Pickup (pallet space)	Delivery (pallet space)
				start	end		
Praha-východ, CZ	Depot	50,1274131	14,6221731	00:00	23:59	---	---
Bělá pod Bezdězem, CZ	Customer 01	50,5012122	14,8041817	03:30	05:00	9	22
Benátky nad Jizerou, CZ	Customer 02	50,2908525	14,8234317	05:45	07:00	9	13
Beroun, CZ	Customer 03	49,9638233	14,0719964	05:15	06:30	3	9
Broumov, CZ	Customer 04	50,5856611	16,3318097	03:30	07:00	8	13
Česká Lípa, CZ	Customer 05	50,6855131	14,5376417	04:00	06:00	3	9
Česká Skalice, CZ	Customer 06	50,3946689	16,0427625	04:45	05:30	11	18
Dobruška, CZ	Customer 07	50,2920133	16,1600131	04:15	06:15	9	16
Doksy, CZ	Customer 08	50,5647128	14,6555250	03:45	07:00	8	9
Dvůr Králové nad Labem, CZ	Customer 09	50,4317219	15,8140211	04:30	07:30	10	13
Frýdlant, CZ	Customer 10	50,9213944	15,0797406	05:00	08:00	9	14
Holice, CZ	Customer 11	50,0660114	15,9858997	05:00	07:00	8	24
Hořice v Podkrkonoší, CZ	Customer 12	50,3660903	15,6318339	04:00	06:30	5	7
Hradec Králové, CZ	Customer 13	50,2092283	15,8327683	05:30	06:30	5	16
Hrádek nad Nisou, CZ	Customer 14	50,8527897	14,8445472	06:00	07:00	8	22
Hronov, CZ	Customer 15	50,4798497	16,1819714	05:45	07:00	0	13
Chlumec nad Cidlinou, CZ	Customer 16	50,1544031	15,4602619	05:15	06:45	8	7
Chrastava, CZ	Customer 17	50,8169256	14,9688361	03:30	06:15	7	23
Chrudim, CZ	Customer 18	49,9510922	15,7955758	04:00	07:00	4	19
Jablonec nad Nisou, CZ	Customer 19	50,7243075	15,1710772	04:45	07:30	9	6
Jaroměř, CZ	Customer 20	50,3561958	15,9213644	04:15	08:00	8	24
Jičín, CZ	Customer 21	50,4372261	15,3516250	03:30	05:00	10	12
Liberec, CZ	Customer 22	50,7699972	15,0584492	04:00	06:30	11	16
Lomnice nad Popelkou, CZ	Customer 23	50,5306247	15,3734103	04:45	07:00	9	9
Městec Králové, CZ	Customer 24	50,2071808	15,2975814	03:30	07:00	11	11
Mimoň, CZ	Customer 25	50,6586886	14,7247361	04:00	06:00	8	21
Mladá Boleslav, CZ	Customer 26	50,4113514	14,9031850	04:45	05:30	0	15
Mnichovo Hradiště, CZ	Customer 27	50,5272047	14,9713353	04:15	06:15	11	22
Most, CZ	Customer 28	50,5030069	13,6361742	03:45	07:00	0	19
Náchod, CZ	Customer 29	50,4167044	16,1628883	04:30	07:30	9	20
Nová Paka, CZ	Customer 30	50,4944939	15,5150317	05:00	08:00	6	17
Nové Město nad Metují, CZ	Customer 31	50,3439522	16,1515464	05:30	06:00	8	6
Nový Bydžov, CZ	Customer 32	50,2415025	15,4908206	06:00	06:30	10	6
Pardubice, CZ	Customer 33	50,0385383	15,7802056	05:45	07:00	1	11
Poděbrady, CZ	Customer 34	50,1424186	15,1188122	04:15	06:00	4	18
Přelouč, CZ	Customer 35	50,0398478	15,5603075	05:15	06:00	7	9
Rychnov nad Kněžnou, CZ	Customer 36	50,1628389	16,2748839	03:30	05:30	10	12
Semily, CZ	Customer 37	50,6019053	15,3355211	04:00	06:15	4	6
Stráž pod Ralskem, CZ	Customer 38	50,7028011	14,8010175	04:45	07:00	8	5
Tanvald, CZ	Customer 39	50,7373536	15,3058536	04:15	07:30	10	22
Teplice, CZ	Customer 40	50,6403975	13,8245072	03:45	08:00	0	23
Trutnov, CZ	Customer 41	50,5610067	15,9127036	04:30	05:00	2	5
Třebechovice pod Orebem, CZ	Customer 42	50,2009683	15,9922311	05:00	06:30	0	15
Třemošnice, CZ	Customer 43	49,8691186	15,5800239	05:30	07:00	9	6
Turnov, CZ	Customer 44	50,5872847	15,1568011	06:00	07:30	3	17
Týniště nad Orlicí, CZ	Customer 45	50,1513633	16,0776972	03:45	05:30	4	6
Úpice, CZ	Customer 46	50,5123742	16,0160675	05:45	07:15	2	14
Ústí nad Orlicí, CZ	Customer 47	49,9738744	16,3936106	05:15	06:15	2	15
Varnsdorf, CZ	Customer 48	50,9115439	14,6182350	03:45	07:00	5	17
Vrchlabí, CZ	Customer 49	50,6269681	15,6093742	04:30	07:30	10	23
Železný Brod, CZ	Customer 50	50,6427400	15,2540775	05:00	08:00	8	7

Source: authors

VRP Spreadsheet Solver applied these limited conditions for this case study: one depot, fifty customers, the fastest route in Bing Maps, the average vehicle speed was set to 70 kilometers per hour, homogenous car fleet with maximum capacity thirty three pallet space, hard time windows type, service time in depot was one hour and customer service time was half an hour.

4. Results

Results of the vehicle routing problem with pickup and delivery with time windows for the case study are presented in the Table 2, there are twenty three vehicles with defined routes to the customers. Every vehicle starts and ends in the depot. The number in brackets indicates the number of pallet space for pickup and delivery in the depot and for each customer. The vehicle 17 serves only one customer (40), other vehicles serve from two to three customers. Three customers serve vehicle number 3, 4, 16, 18 and 21. This is the optimal solution according to entered inputs with the use of VRP Spreadsheet Solver.

Table 2
Solution of the Case Study With Individual Routes and Information About Pickup and Delivery

Vehicle	Route (pickup/delivery)				
Vehicle 01	Depot (33/0)	Customer 29 (9/20)	Customer 04 (8/13)	Depot (0/17)	
Vehicle 02	Depot (32/0)	Customer 07 (9/16)	Customer 13 (5/16)	Depot (0/14)	
Vehicle 03	Depot (33/0)	Customer 36 (10/12)	Customer 45 (4/6)	Customer 47 (2/15)	Depot (0/16)
Vehicle 04	Depot (31/0)	Customer 34 (4/18)	Customer 16 (8/7)	Customer 32 (10/6)	Depot (0/22)
Vehicle 05	Depot (31/0)	Customer 01 (9/22)	Customer 08 (8/9)	Depot (0/17)	
Vehicle 06	Depot (29/0)	Customer 49 (10/23)	Customer 37 (4/6)	Depot (0/14)	
Vehicle 07	Depot (33/0)	Customer 27 (11/22)	Customer 24 (11/11)	Depot (0/22)	
Vehicle 08	Depot (31/0)	Customer 10 (9/14)	Customer 48 (5/17)	Depot (0/14)	
Vehicle 09	Depot (33/0)	Customer 06 (11/18)	Customer 42 (0/15)	Depot (0/11)	
Vehicle 10	Depot (30/0)	Customer 05 (3/9)	Customer 25 (8/21)	Depot (0/11)	
Vehicle 11	Depot (28/0)	Customer 28 (0/19)	Customer 03 (3/9)	Depot (0/3)	
Vehicle 12	Depot (29/0)	Customer 39 (10/22)	Customer 50 (8/7)	Depot (0/18)	
Vehicle 13	Depot (30/0)	Customer 11 (8/24)	Customer 43 (9/6)	Depot (0/17)	
Vehicle 14	Depot (33/0)	Customer 35 (7/9)	Customer 20 (8/24)	Depot (0/15)	
Vehicle 15	Depot (29/0)	Customer 17 (7/23)	Customer 19 (9/6)	Depot (0/16)	
Vehicle 16	Depot (32/0)	Customer 41 (2/5)	Customer 46 (2/14)	Customer 09 (10/13)	Depot (0/14)
Vehicle 17	Depot (23/0)	Customer 40 (0/23)	Depot (0/0)		
Vehicle 18	Depot (31/0)	Customer 21 (10/12)	Customer 31 (8/6)	Customer 15 (0/13)	Depot (0/18)
Vehicle 19	Depot (33/0)	Customer 22 (11/16)	Customer 44 (3/17)	Depot (0/14)	
Vehicle 20	Depot (30/0)	Customer 18 (4/19)	Customer 33 (1/11)	Depot (0/5)	
Vehicle 21	Depot (33/0)	Customer 12 (5/7)	Customer 30 (6/17)	Customer 23 (9/9)	Depot (0/20)
Vehicle 22	Depot (28/0)	Customer 26 (0/15)	Customer 02 (9/13)	Depot (0/9)	
Vehicle 23	Depot (27/0)	Customer 38 (8/5)	Customer 14 (8/22)	Depot (0/16)	

Source: authors

The visualization of the solution for twenty three vehicles and routes is presented in the Fig. 3.

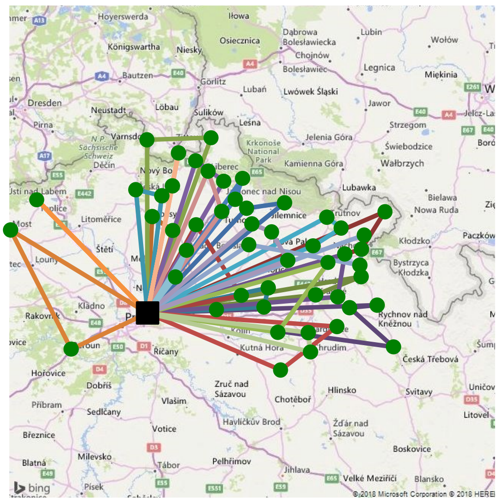

Fig. 3.
The Visualization of the Solution (Twenty Three Vehicles)
Source: authors with use Güneş (2018)

5. Conclusion

In the future can be expected a further increase of traffic intensity due to population growth and population's increasing demands on mobility. The growing boom of e-commerce will lead to greater pressure on distribution logistics and the rising popularity of retail chains, rising sales and higher sales volumes increase the demand for distribution logistics of retail chains. On the other hand, it is necessary to emphasize the need to reduce the negative impacts of transport. One of the potential to reduce the negative impacts of distribution logistics is to use efficient planning tools to optimize the distribution logistics of the retail chain.

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