City Delivery Routes Planning Based on the Ant Colony Algorithm

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Abstract. For any company that sells its products in the networks of city stores, the urgent issue is the optimal delivery of their goods. During routing it is necessary to take into account many restrictions caused by specific conditions of transportation process in the city: number of cargoes, nature of cargoes, delivery time, structure of fleet and its presence, work time of enterprises for load matching, drivers' working hours, loading capacity, road congestion etc. These days, the process of efficient manual routing is difficult because of many restrictions and delivery points wherein it is almost impossible to take into account the road congestion for specific routes. Today's companies are increasingly interested in outsourcing. One of the options for routes planning for enterprises is to use special software products that allow to plan optimal routes according to the chosen criteria and under specific conditions. The process of formation of routes using the Ant Logistics service, based on the Ant Colony optimization algorithm are analysed in the paper. Comparing the two options of forming routes to serve one of the largest retail chains in Kharkiv with the application of Ant Logistics service, it has been elucidated that the application of Ant Colony algorithm is more optimal than the Clarke-Wright algorithm based on delivery routes indicators.

Keywords: freight, city logistics, route, Ant Colony algorithm, transportation costs

Планирование маршрутизации по доставке товаров в городе на основе оптимизации муравьиного алгоритма

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Реферат. Для любой компании, которая реализует продукцию в сетях городских магазинов, актуальным вопросом является оптимальная доставка своих товаров. При маршрутизации необходимо учитывать множество факторов, связанных с конкретными условиями движения транспорта в городе: количество и характер грузов, сроки доставки, структуру парка и его наличие, согласование графика работы предприятия и пунктов погрузки-разгрузки, длительность рабочего времени, грузоподъемность, загруженность дорог и т. д. В настоящее время эффективная ручная маршрутизация затруднена из-за ряда ограничений и большого количества точек доставки, когда практически невозможно учесть загруженность дорог на конкретных маршрутах. Современные компании все больше заинтересованы в аутсорсинге. Одним из вариантов планирования маршрутов для предприятий является использование специальных программных продуктов, которые позволяют задавать оптимальные маршруты в соответствии с выбранными критериями и в конкретных условиях. В статье проанализирован процесс формирования маршрутов с использованием сервиса Ant Logistics на основе оптимизации муравьиного алгоритма. При сравнении двух вариантов формирования маршрутов для обслуживания одной из крупнейших розничных сетей в Харькове с помощью Ant Logistics установлено, что применение муравьиного алгоритма более оптимально, чем алгоритма Кларка-Райта, что основано на полученных показателях работы транспортных средств на маршрутах.

Ключевые слова: груз, городская логистика, маршрут, муравьиный алгоритм, транспортные расходы

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The transportation process organization is one of the significant and complex tasks of delivering finished products to the consumer. Manufacturing companies, transport operators need special software to optimize the delivery process. The importance of information technology for finding effective transport solutions is undeniable [1–4]. In developed countries, the using of software is the usual for organizing the delivery process. At the same time, this practice is not widespread in Ukraine today. Despite the growing interest in such software by businesses, their active use is appropriate to the large companies. First of all, this situation is related with the lack of awareness and complexity of providing cost-benefit analysis of the implementation of special software at the level of small and medium-sized enterprises. The influential factors are also the following:

– relatively low cost of salary, including the logistics manager;

– low margin of business income;

– the relatively high cost of using software products that requires an appropriate scale of business.

Organization of delivery in large cities with a large number of receivers, their differences in requirements to the service makes it impossible to provide delivery only by human resources. The organization efficiency of the transportation process is considered in the context of the effectiveness of the solutions offered by special software products, and more precisely the procedures and algorithms on the basis of which such solutions are offered.

Given this, it is relevant to analyze the capabilities of special programmes (procedures and algorithms that underlie their work) that allow to organize the transportation process of goods, determine their advantages and disadvantages from an economic and technological point of view.

The aim of the paper is to present the efficiency analysis of ant colony optimisation algorithm for planning delivery routes based on the using of specialized software products.

In the first stage, we have analyzed the possible algorithms used in planning of vehicle routes. Thus, it is possible to distinguish methods based on natural approaches. In the paper [2] is defined, that the natural systems that have developed for so long are one of the rich sources of inspiration for inventing new intelligent systems. Swarm intelligence is one of the scientific fields that are closely related to natural swarms existing in nature, such as ant colonies, bee colonies, brain and rivers.

The ant colony optimisation algorithm refers to natural computing. Investigations in this field started in the middle of 1990s. The author of the idea was Marco Dorigo, who proposed to simulate the behavior of an Ant Colony [4]. A detailed analysis and relevance of the application of artificial intelligence technics on transportation is presented in the paper [3], in particular the application of hybrid Ant Colony algorithm to manage bus schedule. The use of the processors' parallel computing capability for routing with the Ant Colony algorithm was determined [5].

And one of the oldest approach for optimal routing planning is the Clarke-Wright algorithm. The CW was proposed by Clarke and Wright [6] who introduced the savings concept which is based on the computation of savings for combining two customers into the same route. This method is a widely known heuristic for solving the vehicle routing problem (VRP), and the applications of the Clarke-Wright have continued since it was proposed in 1964 [7].

Comparison of the efficiency of the software using such as Ant Logistics (Ukraine), Maxoptra (Russia), Logist Instrument (Russia), Begunok (Russia) is presented in [8], with cost-benefit analysis of their use.

Let's consider two options of the routes formation: the first is based on the use of Ant Colony algorithm, the second is using the Clarke-Wright method.

The process of forming the routes are considered in Kharkiv while delivering the products in ATB trading network. It is one of the largest retail chains in Ukraine. The ATB sales network is a discounter store offering a wide range of food and non-food product groups at optimum cost. It covers 22 regions in Ukraine, has two distribution centers, more than 1000 stores in 256 settlements, 55 of which are located in Kharkiv. Every day more than 3 million Ukrainians do the shopping at ATB stores. According to the results of 2018, the company's turnover is about to $ 3.9 billion. For this company, the process of product delivery is one of crucial point. Delivery of goods is carried out by own transport of the company from the distribution centre to the shops, and also from a supplier to the

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Then worked with the tab page "Vehicle" and input the required number of vehicles. In the properties of each vehicle it is possible to specify the name, nominal and maximum load capacity in tons and meters cubic, average speed of movement, mode of operation of the vehicle, freight forwarder, additional restrictions (Fig. 3). Also, it is possible to specify tariffing at the cost calculation per 1 km or per 1 ton.

Next, in the settings indicated the time of unloading. Accounting cargo in 1 kg (weight) was selected in the tab "Accounting". The importance of overloading the vehicle is very high.
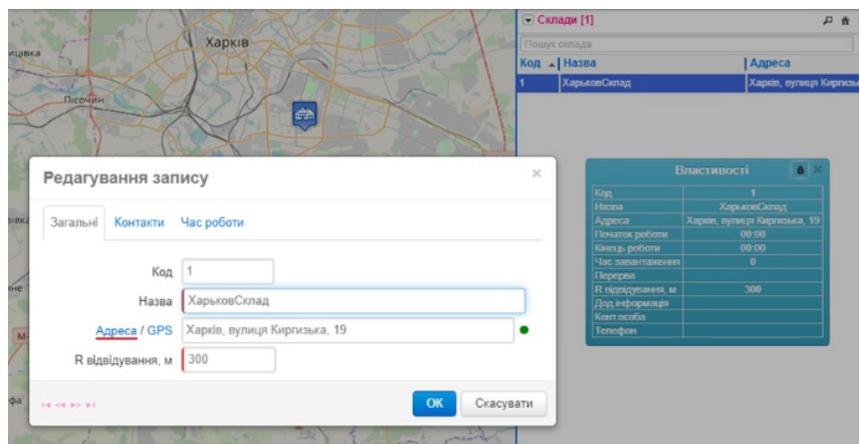
The next step in the tab "Commodity Groups" is to set the loading/unloading time in the "General group" properties. Thus, the total delivery time of the vehicle at the retail point was calculated by the service according to the following formula:

$$T_{tot} = T_{adm} + \frac{Q_{ord}}{K_{load/unload}}, \qquad (1)$$

where T_{adm} – administrative time spent of the vehicle at the retail point, min; Q_{ord} – order size, kg; $K_{load/unload}$ – loading/unloading velocity of vehicle at the retail point or distribution centre, kg/min.

Routes are formed on the basis of Ant Colony optimisation algorithm. The ant characteristics are the following [4]:

(i) Each ant has its own "memory," which contains the list of the cities $J_{i,k}$ (the taboo list) that should be visited by the kth ant, which is in the ith town;

(ii) ants have their "vision" inversely proportional to the edge length

$$n_{ij} = \frac{1}{D_{ij}}. \qquad (2)$$

The vision determines the "greediness" of the ant choice. The closer a graph node, the better its visibility and the higher the agent desire to reach it;

(iii) all ants can catch the pheromone trails, which stimulates the ant desire to pass a given edge. The pheromone density on the edge D_{ij} at the time t is $\tau_{ij}(t)$;

(iv) the probability that an ant chooses the path from the ith node to the jth node is given by the expression:

$$\begin{cases} P_{ij,k}(t) = \dfrac{\left[\tau_{ij}(t)\right]^\alpha \left[\eta_{ij}(t)\right]^\beta}{\sum_{l \in J_{i,k}} \left[\tau_{il}(t)\right]^\alpha \left[\eta_{il}(t)\right]^\beta}, & j \in J_{i,k}; \\ P_{ij,k}(t) = 0, & j \notin J_{i,k}, \end{cases} \qquad (3)$$

where α, β – parameters specifying the weights of the pheromone trails and the heuristic coefficients.

The parameters α and β present the relative significance of two factors and their influence on the equation. They determine the ant greediness. At $\alpha = 0$, the ant aspires to choose the shortest edge; at $\beta = 0$, the ant aspires to choose the edge with maximum pheromone density. It is easy to notice that this expression describes a roulette wheel.
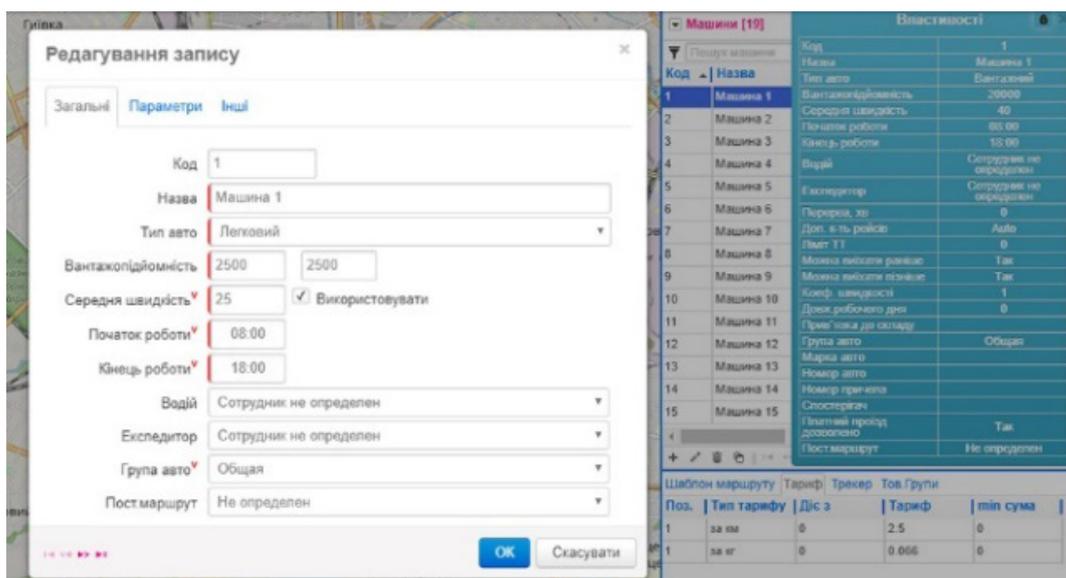

Fig. 3. Data of vehicles

The left panel of Fig. 1 shows a graph and the right panel presents the distribution of the probabilities of the passages from the first node to the others. Here, α = 1, β = 1, and the edge thickness shows the pheromone density on the edge. As α increases, the probability of choosing the edges with a higher pheromone density increases. As β increases, the probability of choosing shorter edges increases and the probability of choosing longer edges decreases.

The probability of choosing the shortest path increases with time, because the pheromone density is inversely proportional to the path length and is specified as:

$$\Delta\tau_{ij,k}(t) = \begin{cases} \dfrac{Q}{L_k(t)}, & (i,j) \in T_k(t); \\ 0, & (i,j) \notin T_k(t), \end{cases} \quad (4)$$

where Q – parameter with the value of order of the optimal path length; $L_k(t)$ – length of the path $T_k(t)$.

Pheromone evaporation is described by the expression

$$\Delta\tau_{ij,k}(t+1) = (1-p)\tau_{ij}(t) + \sum_{k=1}^{m}\tau_{ij,k}(t), \quad (5)$$

where m – number of ants; p – evaporation coefficient $(0 \le p \le 1)$.

In this case, the initial state of the Ant Colony is specified as follows: the number of agents is equal to the number of graph nodes and each agent has a node from which it starts the tour.

The list of receivers is formed in the Excel file, with the name, location, volume, mode of operation, contacts of the responsible person, etc. After the file is uploaded, the users are automatically linked to the service map using the Open Street Map database. The route is then calculated. Thus, routes were obtained with the parameters entered (Fig. 4.)

It is possible to analyze the performance of transport using interactive dashboard of the analytics: the cost of each vehicle, number of stops etc. (Fig. 5).
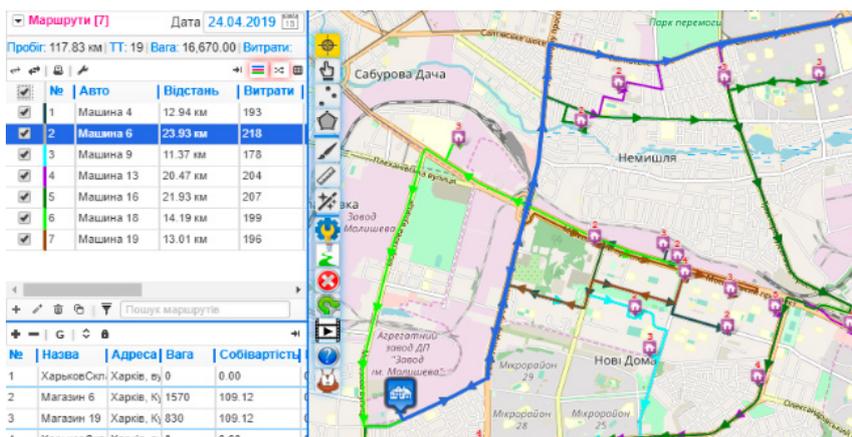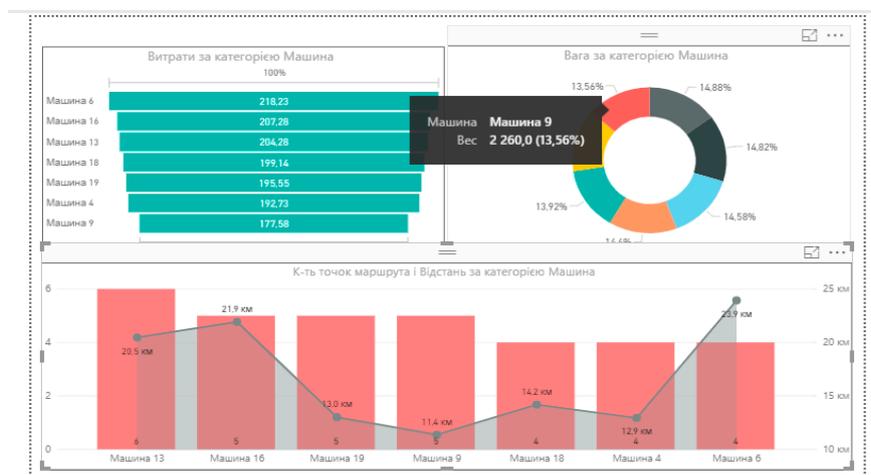

Fig. 4. Routes developed

Fig. 5. Interactive dashboard of the analytics

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Let's consider the second option of the route formation programme based on the using of the Clarke-Wright algorithm. The program name is VRP. The algorithm of the VRP program is shown in Fig. 6 [10].
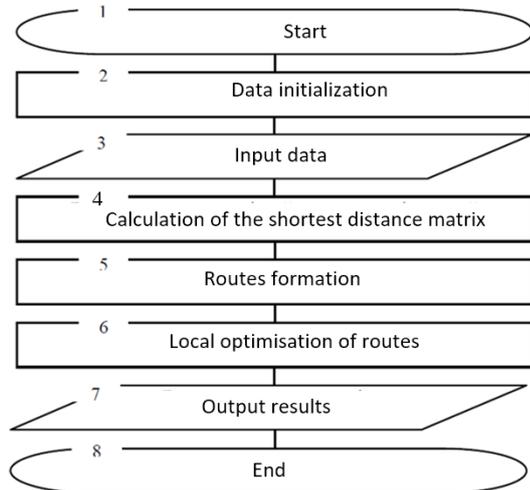

Fig. 6. Routing program algorithm of VRP program

The program takes into account the parameters of the transport network (delays at intersections, velocity, existing schemes of traffic organization), parameters of participants of logistic process (order size, their dislocation, number of orders, working hours), cargo parameters (size, dimensions, physical properties, transportation requirement), vehicle parameters (capacity, dimensions, performance).

In the list of indicators that allow to take into account the specifics of the delivery process both programs are just about identical.

According to the algorithm at the third stage data is input after the initialization. The program is written in Delphi language using the module Net.exe.

Using this VRP program, distribution routes were formed while servicing ATB's retail stores (Fig. 7).

In this case, it was also received 6 delivery routes, but the order of arrival to the shops is different compared to using the Ant Colony algorithm. Therefore, the performance of vehicles is different (Tab. 1).

Table 1

Comparison table of delivery routes indicators

Indicator	Algorithm	
	Ant Colony	Clarke-Wright
Capacity of vehicle, t	2	2
Number of routes	6	6
Routes length total, km	51.12	59.03
Size of cargo, t/week	11.5	11.5
Number of shops	55	55
Total distance, km	306.72	354.19
Delivery time, hour	25.23	28.62
Cargo turnover, t·km	589.27	662.51
Load factor average	0.96	0.93

Comparing the results, it can be concluded that with the use of the Ant algorithm, the total mileage is lower by 13.4 %, the service time less by 11.8 % and the turnover less by 11.0 %. Capacity factor is not significantly different. The obtained figures show that by applying the Ant algorithm it is possible to obtain more rational routes in comparison with the Clarke-Wright method.

Significant advantages of using the Ant Logistics server in the context of practical application is the use of Open Street Map maps, which allows you to get routes for real conditions of transportation. It is also possible to calculate the cost of delivering the cargo, with the cost per 1 ton or per 1 km of mileage for each vehicle or routes for a specific period separately.
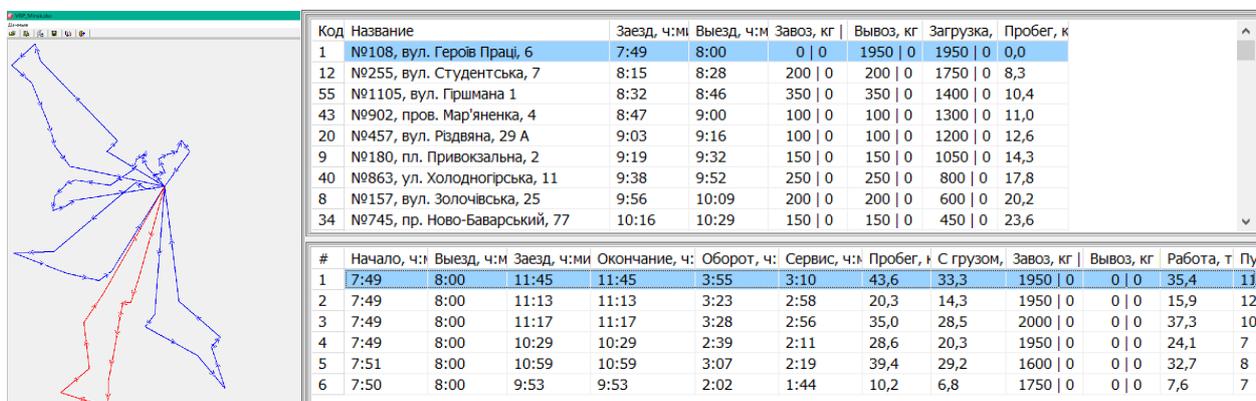

Fig. 7. VRP routing program

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The disadvantages of the considered information resources can be attributed to the lack of ability to assess the environmental impact of the proposed solutions. At the same time, this situation is usual for commercial products focused on business.

CONCLUSIONS

1. The application of special software for the organization of delivery process within the city becomes a prerequisite for ensuring the technological and economic efficiency of the transportation process. Technological efficiency is conditioned by the using of the optimal algorithm and, as a rule, provides the best economic performance of the transportation process.

2. Comparing the two options of forming routes to serve one of the largest retail chains in Kharkiv with the application of special software, we elucidate that the application of Ant Colony algorithm is more optimal than the Clarke-Wright algorithm. In particular, the overall mileage is lower by 13.4 %, with more than 10.0 % advantage in terms of service time and turnover.

3. From a practical point of view, the main benefits of special software are the ability to plan, control and re-schedule delivery routes in real time, taking into account road and delivery conditions. The disadvantage can be considered the complexity of economic justification for the feasibility of using special software products, as well as the cost of such service.

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