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Multi-objective optimization of delivery schedule to design and plan distribution services in urban areas

1. INTRODUCTION

Distribution of cargo to customers means a planning and control of the physical movement of finished products to customers, which should be organized at the lowest possible cost and in a timely manner. Specific conditions is for distribution taking place in cities because it is an important factor for economic and social development in urban areas [12]. On the other hand, causes a local community concerns related to traffic safety and increased traffic. However, well-organized transport is a stimulant for economy [9].

Distribution of cargo as an extensive research area requires consideration of many points of view which should be represented directly or indirectly in the form of criteria for evaluating such system. Among the issues due to which considers the cargo distribution should take into account the efficiency and reliability of systems, ecology transport, methods and ways of organizing the distribution and attention to reducing costs and ensuring timely implementation. The issue of cargo distribution requires in addition consideration of economic factors, the problem of infrastructure availability, traffic safety or the stochastic nature of traffic [5].

It is important to develop methods positively influencing on the distribution process which will contribute to the reduction of transport work in the city. The search for methods of planning, it is important also for the whole supply chain and its individual cells. In that view, it is extremely important to route planning that is directly related to the scheduling of drivers work [26]. This matters are combination of VRP dependent of the organizations used in the distribution system. In this article we consider concepts based on multistage distribution systems. This approach allows for a reduction of transport work undertaken in the city and in particular to reduce the high tonnage vehicles [13], but it must be well justified economically. This involves the possibility of using it only in large cities and agglomerations.

2. FORMULATION OF THE CARGO DELIVERY OPTIMIZATION PROBLEM IN MULTI-OBJECTIVE ASPECT

Due to the necessity to improve the quality cargo transport in urban areas and in the improvement of its efficiency, it is necessary to seek ways of organizing the distribution of goods that reduce transport work. Related to this is also a better use of the means of transport, as well as lower operating costs of the service provider [23].

One method of services organization is to use a multistage distribution systems. Distribution cargo takes place through warehouse facilities located on the outskirts of the city (cargo consolidation centers - CCC), as well as within its borders (HUB). These facilities serve such features as storage, picking, or distribution of loads on individual routes (for smaller vehicles). Among multistage distribution systems should be distinguished one-tier, two-tier and the mixed system [11], [19].

In the two-tier distribution system cargo consolidation center (CCC) serves as cargo sender. Storage facilities are located outside the city. Intermediate element (the second level of the hierarchy) are HUBs, which are located in the industrial districts of cities, and their location provides both a good

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connection with the recipients and with the CCC. Deliveries from CCC after picking goes to the HUBs. There charges are again handled and delivered to customers.

Including direct deliveries in distribution system transform it into a mixed system (Figure 1). Thus, there is distribution using two levels and one level of distribution. The system also realize that CCC (next to the warehouse activities) picking operations (by order recipients) and distribute loads to customers located in the city. The distribution of loads in CCC-recipient relations applies low-tonnage vehicles [1], [4], [11].

![Diagram](image_url)

**Fig. 1.** Multistage distribution systems serving recipients located in urban areas

*Source:* [24].

The selection of distribution vehicles in each of the systems is primarily dictated by the need to ensure flexibility in the implementation of services. Vehicles are selected in a way allows to avoid the constraints of city transport network (permissible gross vehicle weight on a particular route), as well as restrictions on driving time (as in the case of vehicles with GVW> 3.5t).

In multistage distribution systems organization uses a regionalization of customer service. In the case of the presented concept does not include such an approach. It significantly limits search for cost effective solutions and will wander among local minima (in terms of cost).

In the presented systems is the possibility to add another level as an transport between HUBs. The system will then stand HUBs hierarchical which means parent and child. However, in cities, it is unusual form of organization of the distribution.

Multi-criteria optimization task is to formulate a vector criterion function consisting of partial functions seeking to extreme, for example 

$$F(\{f_1, f_2, f_3\} = \{f_1(x), f_2(x), f_3(x)\}).$$

The function in this form is the subject of this article. Possible solutions of formulated optimization task are classified in the solution space that is dominated and non-dominated (Pareto optimal). Such solutions are feasible solutions characterized by improving the value of one of the criteria at the expense of the deterioration of the value of other [10]. Choosing a solution depends on the individual preferences of the decision maker which is intended to restrict the space of acceptable solutions.

**Vector criterion function consisting of partial criteria was defined (Formula 1):**

$$F(G1, G2, G3) = \begin{bmatrix} E(G1(X4, XC, YA, YB)) \rightarrow \text{min} \\ G2(XA, XB) \rightarrow \text{max} \\ G3(XA, XB) \rightarrow \text{min} \end{bmatrix}$$

(1)
The first partial function is a $G_1$ (formula 2), refers to minimizing the cost of transportation plan. In order to ensure the simplicity of the record it was divided into five components respectively, $G_{11}$, $G_{12}$, $G_{13}$, $G_{14}$, $G_{15}$. Wherein the function $G_{14}$ and $G_{15}$ were further divided into three parts. It takes into account the cost of operation of storage facilities $C(G_{11})$ and HUB ($G_{12}$), the cost penalty for delays and in the lack of service of the recipient ($G_{13}$), shipping and handling charges resulting from the mileage of vehicles ($G_{14}$) and the working time of drivers ($G_{15}$). Some of the data included in the criterion function are random variables, and to determine the functions $G_1$ used their expected value $E(s)$. This causes that the function $G_1$ will also be the expected value of the cost of implementing the deliveries plan.

$$
E\left(G_1(X_4, X_3, Y_B)\right) = \left[ G_{11}(X_4) + G_{12}(X_4) + E(G_{13}(X_4, X_C, Y_B)) + \\
G_{141}(X_4) + E(G_{142}(X_4)) + E(G_{143}(X_4, Y_A)) + \\
G_{151}(X_4) + G_{152}(X_4) + G_{153}(X_4, Y_A) \right] (2)
$$

One of the most important factors affecting the quality of service is the realization of anticipated transportation plan. By this its mean handle or not handle clients in accordance with the agreed schedule, at designated intervals [4]. Under this assumption formulated two other criterion functions are associated with the probability of a correct implementation of the plan of carriage. Functions $G_2$ and $G_3$ are divided into two parts respectively $G_{21}$ and $G_{22}$, and $G_{31}$ and $G_{32}$. This is because the separation of functions representing the component routes which is supported only one recipient and routes where there are more customers served.

The $G_2$ (formula 3) is the probability that a scheduled recipients service will be held on time windows.

$$
g_2(X_A, X_B) = \prod_{b=1}^{B} \left[ \mu(b) \cdot G_{21}(X_A, X_B) + \lambda(b) \cdot \left\{ G_{21}(X_A, X_B) \cdot \prod_{c=2}^{C} G_{22}(X_A, X_B) \right\} \right] (3)
$$

When the supply plan shows that the recipient (based on economic calculation) is to be served outside the time window for such a component a $G_2$ function must be set to 1.

The $G_3$ (formula 4) is the probability that customers planning to services will not be served which cause increase the costs. Do not handle customers may be caused only by exceed the close time in each recipient. However, recipient do not must be included in the delivery schedule which could be the result of economic calculation. $G_3$ function is defined as the risk of not handle planned recipients. It is assumed that the recipient is not served if it was not provided to him in a number equal to the charge of his demand.

$$
g_3(X_A, X_B) = \prod_{b=1}^{B} \left[ \mu(b) \cdot G_{31}(X_A, X_B) + \lambda(b) \cdot \left\{ G_{31}(X_A, X_B) \cdot \prod_{c=2}^{C} G_{32}(X_A, X_B) \right\} \right] (4)
$$

$G_2$ and $G_3$ functions are apply only to customers whose handle was planned. The cost function takes into account all the recipients reporting requirements and the cost for not handle recipient included in the penalty function.

Factors $\mu(b)$ and $\lambda(b)$ determine the type of distribution routes realized. If on run is one served client $\mu(b) = 1$ and $\lambda(b) = 0$ otherwise, ie. when on the route is more than one client $\mu(b) = 0$ and $\lambda(b) = a$ this generates the assumption that $\forall b \in \bar{B} \quad \mu(b) + \lambda(b) = 1$.

Therefore, must be determine the value of each decision variables to partial function values seek to local extremes in such a way that the global vector function seek to pareto optimal solutions. Those decision variables characterized as follows:

- $X_A = [X_1, X_2, X_3, X_4]$ - volume of cargo stream between points of origin and destination
- $X_B = [XTSA, XTSB]$ - the time of the beginning $b$-th run in distribution process realized form CCC and from HUB
- $X_C = E(XTSO)$ - expected time of the beginning of the recipient service
- $Y_A = [Y_1, Y_2, Y_3]$ - binary variables determining the existence of a return connection on all transport routes
- $Y_B = [Y_4, Y_5]$ - planned to delay or not handle customers

To solve the formulated task it is necessary to determine the input data:
- the structure of the transport network, set of supplier (CCC), intermediate points (HUB) and recipients;
- the distance between individual elements of the transport network
- the value of the expected travel time which is a combination of random variable with known distribution;
- the expected duration of the loading operations at the CCC, at HUB, and the recipients of which is a random variable with known distribution;
- recipients demand;
- the time windows of the recipients;
- the costs, including:
  - fixed costs - CCC functioning, HUBs functioning, single run of the vehicle, the driver's employment;
  - unit costs - the flow unit load through CCC, through HUB, the driver's employment, transport of one unit for different relation, empty runs;
  - the penalty costs: for delays in the recipient services, lack of service for a given recipient;
- CCC and HUBs capacity in the number of unit loads;
- capacity of vehicles;
- GVW (gross vehicle weight);
- the maximum daily working time of a given type of driver;
- number of available vehicles of a given type;
- number of available driver of a given type;

When solving the tasks it is necessary to meet constraints arising from the characteristics of the transport network and the characteristics of its elements. It should take into account, inter alia, the following restrictions and assumptions:
- events described by random variables are independent;
- the volume of supplies to the recipient cannot be higher than the demand;
- volume of supplies coming from the CCC to HUB must be equal to the size of outbound deliveries from HUB;
- number of cargo coming from the CCC cannot be higher than the demand of recipients;
- vehicle capacity during the course cannot be exceeded;
- a vehicle leaving the CCC must return to it;
- a vehicle leaving the HUB must return to it;
- number of cargo outgoing from CCC cannot be greater than its capacity;
- number of cargo outgoing from HUB cannot be greater than its capacity;
- driver's working time cannot be exceeded;
- correct service begins and ends in a time window;
- customers can be services fully, partially or not at all.

Formulated criterion function takes into account the interests of many participants of the transport process carried out in the city, it is including suppliers, carriers, recipients and inhabitants. Properly planned operation reduces transport work done in the area of the city, reduces operating costs of the carrier, and hence the cost of transport, and also affects the quality of service and customer satisfaction. Less traffic in the city are also benefits to the citizens even in the form of increased security and reduce pollution.

The optimization task is presented in the implicit form which have to provide to indicate the area of search for a solution. Do not focus on the production of formal writing mathematical model because of its extensive and complex record [25].
The constraints presented in the description of the mathematical model are supported by the use of certain operations in order to restrict the search unreasonable solutions. In order to narrow and clarify the space of possible solutions introduced variable cost of switching units of cargo by HUB storage facilities and CCC. Introduced feature allows to eliminate the use of objects with negligible material flow (and ultimately eliminate them from the structure of the system). An example of the graph of the cost of the material flow in storage facilities is shown in Figure 2. It is worth to notice that the function is decreasing in the shown range. However, there is the threshold for which with the number of units of cargo costs do not decrease (not marked on the chart). It is also possible shape of the function at certain intervals where there is a sudden increase in cost (the necessary investment), and then as the flow increases further decrease.

![Graph](image.jpg)

Fig. 2. Chart of cost of moving cargo unit through a warehouse facility depended on total material flow

Source: [24].

In order to introduce further restrictions as found solutions adopted for fixed cost of the indirect route allows to reduce the number of vehicles and drivers.

Variable cost of supply in the city was taken as independent of the volume of traffic, but only on kilometers traveled by delivery vehicles. This is due to the specific nature of the distribution [24].

This article is limited to the presented model in order to present a concept of method developed to resolve it. Developed a heuristic method is also applicable to more complex optimization models, although it requires some modification.

3. Multi-objective problem of scheduling delivery process

Based on the concept of the presented model it is possible to formulate a many optimization tasks, taking into account the different criteria and constraints. It should be emphasized the classic problem of the cargo distribution for the lowest cost, but also, for example implementation of criteria related to emissions. Certain criteria clearly define the issue and the point of view of whether logistics operator or inhabitant. Formulated task also required to adopt certain limitations to allow for mapping the real problem as precisely as possible. To solve the task, it is necessary to adopt the constraints and assumptions including, for example capacity, working time, or restrictions on the transport network connections.

The above information allows to classify the formulated problem. Therefore, research in this article applies to modified problem VRP (Vehicle Routing Problem). This task is based on the traveling salesman problem often described as the TSP, and more specifically on the modification of the so-called problem of MTSP (Multiple Travelling Salesman Problem). In contrast to the problem in the task MTSP each transport VRP (vehicle) has a defined capacity and customer demand [21]. Thus, the total demand of customers cannot exceed capacity means of transport. Generally the solution is to
minimize the number of vehicles, the number of routes and the total length of the route [6], [7]. Presentation of these problems is shown in Figure 3.

Taking into account the adopted model assumptions, constraints and criteria functions in the article was made a combination of different varieties of problems belongs to VRP class:

- **MOVRPTW** – Multi-objective vehicle routing problem with time windows
- **MDVRP** - Vehicle routing problem with multiple storage facilities
- **SVRP** - Supply problem with random data
- **HVRP** - Deliveries are made by vehicles with different capacity

The solution of the formulated task meets three major problems of optimization and decision-making. The first issue is the superior multi-criteria optimization. Another one is the problem of determining the order of customers visited which means vehicles and drivers scheduling and the choice of routes between points in the transport network.

Identified problems can be solved with the use of advanced and modern methods of optimization algorithms based on accurate, heuristic or hybrid [15], [16], [17], [18], [27], [29]. To solve the methods can be used methods also successfully used in other areas for example rail transport [8] and storage [13].

![Fig. 3. Presentation of TSP, VRP and MDVRP in deliveries problem area](source)

**Source:** [5].

4. **EVOLUTIONARY METHOD IN MULTI-OBJECTIVE CARGO DELIVERY SCHEDULING**

Among the most important problems to be solved in the formulated task should be distinguished:

- multi-objective optimization problem
- scheduling of deliveries including the order of visited points

The optimization problem including the three criteria requires finding solutions acceptable from the point of view of each of them. The ideal solution is one that is best for each objective function, but in practice such a solution is achievable rarely. This optimization can be carried out by conventional methods, eg. The method of weighted objectives or restrictions or heuristic method such as VEGA (Vector Evaluated Genetic Algorithm) or SPEA (Strength Pareto Evolutionary The Algorithm) [14].

The delivery scheduling is directly connected with the vehicle routing or determining the order of visiting customers, depending on the time window and the recipient's needs taking into account the travel times, loading times or work time and the type of vehicle involved. Algorithms for solving the problem can be divided into precise drawing optimal solution, as well as heuristic algorithms which return a suboptimal solutions otherwise rational. Accurate algorithms, tend only to brute force search of possible solutions which is not efficient for large tasks because the presented problem belongs to the class of NP-hard problems. Therefore, it is necessary to use heuristic algorithms, and here we can...
distinguish for example genetic algorithms, bee, bat or ant. It is also possible to use algorithms based on artificial neural networks but it requires having extensive database supporting the learning of such network [2], [14], [22].

The combination of these two elements requires the use of an appropriate method for a quick way to determine a set of non-dominated solutions containing acceptable solutions from the point of view of optimization tasks.

To solve presented problem it was decided to use a genetic algorithm which mapped representation of solutions in the form of trees. This is shown in Figure 4.

![Population](image)

**Fig. 4.** Tree with representation of individuals and population in genetic algorithm

*Source: own work.*

In this method, each branch of the tree represents population, which consists of journeys carried out for a given C (Cargo Consolidation Center) by H (HUB) to R (Recipient). As it is known, the most important operators in genetic algorithm is crossing and mutation.

In the present approach, each individual represents exactly one route provided from the HUB supplied from CCC. It is possible to use the crossing at three levels within a single population. The first crossing involves the exchange of the recipient (single gene) in the delivery of the same HUB but on two different routes. The next level is the replacement of the entire route between HUB from which they are implemented. The next level involves the exchange of the CCC, which supply HUB and set route. Mutation can be done at any level, where the number of a single gene changes. It can be implemented for both the CCC, HUB and the recipient.

This method is applicable for single objective solution. Expansion it to more criteria requires an additional set of solutions non dominated. The algorithm is based on a multi-criteria method SPEA [28]. Here, assumes the possibility of crossover and mutation rate between the best populations.
The use of trees to represent individuals is important from the identification and application reason. Allows for easier and more effective implementation of operators which improve the results and thereby contribute to finding solutions closer to Pareto optimum.

Solution task consists in find the delivery schedule. Example of schedule is shown in Figure 5. It presents the driving time and cargo unloading time in points (green). This way of presenting the results is clear and easy to qualitative analysis solution. Ultimately, any schedule can be represented from the view, ie each CCC, HUB, Recipient, as well as a single vehicle and driver.

![Fig. 5. An example of deliveries schedule obtained from calculations](source: own work)

5. CONCLUSION

Cargo distribution systems containing many elements which have a significant impact on the quality of the executed service. It is therefore necessary to use methods to take into account all relevant assumptions, limitations, and in terms of the multi criteria point of view of many participants in the process of distribution. Presented in the work multilevel distribution model only indicates the area of research. Specifically formulated the task is very complex and complicated especially in connection with the functions based on the probability. Therefore, it is presented in the implicit form.

The model described in this paper allows to specify the main issues to solve the formulated task. Among the main problems that exist in this type of task. Here indicated a problem of the best path search, the vehicle routing problem (VRP) and the problem of finding non-dominated solutions which is multi-criteria optimization.

The problem of scheduling in this case belongs to NP class. Therefore requires the application of methods to draw solutions to meet the requirements of the decision maker in acceptable time of computation.

Therefore, it was necessary to develop the concept of own or modified of existing matching algorithms to solve a particular case. As part of the research it was decided to modify the heuristic algorithms and more specifically the use of genetic algorithm modification (with a specific approach Pitsburg and construction of the tree) and SPEA algorithm.
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Streszczenie

Dystrybucja ładunków jako istotny element łańcucha dostaw wymaga stosowania ujęcia systemowego, aby uwzględnić funkcjonowanie wielu elementów i ich wpływ na końcowy efekt realizacji dostaw. W dystrybucji ładunków niezbędne jest uwzględnienie kosztów jej realizacji, ale także innych kryteriów determinujących jej organizację. W pracy założono zastosowanie problematyki wielokryterialnej, aby lepiej odwzorować rzeczywistą charakterystykę funkcjonowania takich systemów.

W artykule przedstawiono ogólny heurystyczny model dystrybucji ładunków w systemie wieloszczeblowym. Oparty jest on o Centra Konsolidacji Ładunków, HUB’y przeladowunkowe oraz odbiorców ładunków. Jakość zastosowanego rozwiązania oraz dobranego planu dostaw jest oceniana w oparciu o koszty oraz prawdopodobieństwo realizacji zadań.

Sformułowany problem należy do zagadnień typu VRP (Vehicle Routing Problem), a dodatkowo wzbogacony został o wielokryterialną funkcję kryterium. Rozwiązanie takich zadań wymaga stosowania efektywnych metod zwracających rozwiązanie w akceptowalnym czasie. W związku z powyższym zaprezentowano koncepcję zastosowania algorytmów ewolucyjnych bazujących na algorytmach genetycznych w harmonogramowaniu dostaw.

Słowa kluczowe: problem trasowania pojazdów, VRP, optymalizacja wielokryterialna, logistyka miejska, harmonogramowanie dystrybucji

Wielokryterialna optymalizacja w harmonogramowaniu dostaw i planowaniu dystrybucji w obszarach miejskich

Abstract

Distribution of cargo as an essential element of the supply chain requires the systemic approach to include the operation of many elements and their influence on the final result of delivery. In cargo distribution, it is necessary to take into account the costs of its implementation, but also other criteria that determine its organization. The study assumes the use of multi-criteria problems in order to better map the actual characteristics of the operation of such systems.

This paper presents a general heuristic model of cargo distribution in multilevel system. It is based on Cargo Consolidation Centres, HUB’s and recipients. The quality of the used solution and the chosen delivery schedule is evaluated based on the costs and the probability of the tasks realization.

Formulated problem belongs to the issues of VRP (Vehicle Routing Problem), and additionally was enriched with multi-criteria function. The solution of such tasks require the use of effective methods to return a solution within an acceptable time. Therefore, in article was presented concept of the use of evolutionary algorithms based on genetic algorithms to schedule deliveries.

Keywords: vehicle routing problems, VRP, multi-objective optimization, city logistics, distribution scheduling

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