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Decision Support System in Freight Transport Based on Vehicle Routing Problem with Quality Criterion

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ABSTRACT

Deliveries planning in transport systems is a complicated task and require taking into account a wide range of factors. Enterprises wanting to propose solutions that meet the clients' needs and be competitive on the market must prepare their offer based on decision support systems including factors characteristic for the real process. The aim of the article is to present a concept of a decision support system based on a multi-criteria vehicle routing problem in real conditions (Real-World VRP). Taking into account the latest trends in the optimization of the delivery plan, the model includes three criteria - the cost, time and success rate of the delivery plan as a criterion relating to the quality of the delivery plan. Among other assumptions, it should be pointed out that the heterogeneous structure of the rolling stock has been taken into account, the number of which is not limited, the vehicles return to the place of origin. The travel time of the connection and the time of loading operations are random variables. The limited driver's work time and driving time were also applied. The effect of the work presented in the article is the concept of the decision support system in the freight transport, taking into account the quality criterion of the delivery plan.

KEYWORDS: decision support systems, vehicle routing problem, VRP, optimization

1. Introduction

Road transport has the main share in the transport of cargo in comparison to other modes of transport. On the one hand, a well-organized transport of goods is a factor stimulating the economic and social development of countries, regions, and cities, on the other hand, is a significant generator of noise, accidents, pollution, etc., which contributes to lowering the quality of the environment [19, 6]. This is especially evident in large urban agglomerations, where traffic is high and traffic safety is becoming more and more threatened. Traffic safety, minimization of congestion on roads and minimization of environmental pollution by transport activities are particularly important in the development of freight traffic organization plans [31, 18].

The freight transport combines the issue of organization of supply services for various types of entities, including: supplying large shopping centres, stores of various industries, restaurants, work and leisure places, small-scale outlets and municipal waste shipments. In order to reduce the negative impact of transport, methods and tools are being sought to support proper planning and organizing transport. A good organization of the transport service of the recipients allows for a reduction of transport work, and hence a reduction of costs, increased safety and improvement of the quality of services [31, 13, 22].

The organization of cargo distribution requires the use of appropriate decision support tools. They can be described as decision support systems (DSS) [28]. These systems are dedicated to increasing the quality of decisions made based on the knowledge from information technology, including mathematical models and optimization algorithms. In cargo distribution processes is a very important class of problems called VRP (Vehicle Routing Problem) formulated by Danzig and Ramser in 1959) [5]. Since 1959, many works devoted to VRP and its modifications have been made. This problem is extremely interesting due to its computational complexity (NP-difficult problem), as well as its practical application. Areas of application mainly include industry, logistics and telecommunications network design.

The purpose of the article is to present the concept of a decision support system in the distribution of cargo, taking into account different decision criteria. The article was divided into an introduction and 5 sections. In second section, the issues of distribution organization and conditions of transport implementation are presented. The third section presents a short description of optimization models from the VRP family being the basis for considering the distribution problem, as well as a short review of methods for solving them. Concepts of the decision support system along with the assumptions of the mathematical model and a calculation example are presented in part 4. Section 5 contains conclusions and directions for further work on a comprehensive decision support system.

2. Problems of cargo distribution organization

The organization of transport should be considered on many levels. It is necessary to take into account the interests of all participants in the distribution process related to it either directly (operators, clients) or indirect (final consumers, residents of areas where transport takes place, road users). Transport planning requires actions aimed at minimizing its negative impact and at the same time increasing efficiency. These activities can be carried out at various levels. Schoemaker and Hamel [17] propose the use of a cascade model in which they distinguished 4 main levels on which the consumption of resources should be limited:

- transport demand and supply - the amount of cargo to be transported,
- vehicle traffic - necessary transport work to meet demand,
- energy consumption and emission of pollutants and noise,
- consumption of fossil fuels - level of exposure.

The Trail Layer Model is a similar solution indicating areas in which actions to increase the efficiency of transport should be taken [33]. In this model, 5 layers have been distinguished:

- transport market - describing the potential demand for transport.
- load - related to particular types of transported assortment.
- loading units - related to the transport form of the load.
- means of transport - including means of transport used to transport loads of different properties.
- infrastructure - covering all facilities in the logistics network affecting the implementation of transport by means of transport.

The model takes into account the relations between the layers, with each layer having the ability to analyze the range of transport impact on the environment through the prism of such elements as: society, resources, technology and management. The scheme of the Trail Layer Model model is shown in Fig. 1.

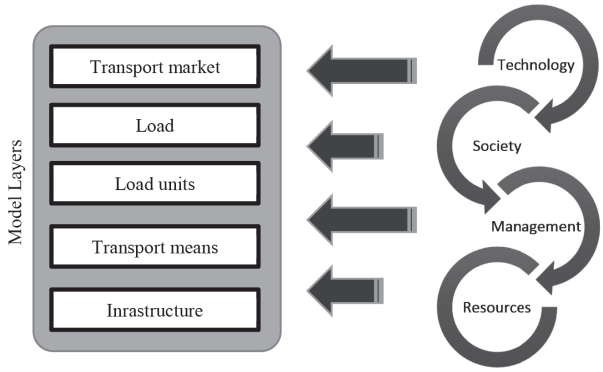

Fig. 1. Diagram of a layer model TRAIL [33]

As indicated in the presented models, the main emphasis is put on the use of available resources, this leads to the goal of moving while maximizing its efficiency. However, resource management must be carried out in a manner that ensures the desired level of service quality, while minimizing internal and external distribution costs.

Undoubtedly, the logistics service of various areas is a complex issue, due to their complexity and various characteristics, including for example:

- population density, i.e. a broad spectrum of consumers
- the labor market, including employee availability and employment costs,
- a density of buildings,
- characteristics and availability of road infrastructure as well as its condition,
- spatial barriers,
- restrictions on the development of transport infrastructure and high investment costs,
- environmental protection (emission of pollutants and noise).

As Jacyna et al [19] pointed out, the functioning of the distribution system is associated with its negative impact on the environment. It mainly occurs as emission of exhaust gases into the atmosphere and excessive noise [21, 35]. In addition, other negative effects include congestion, impact on the safety of other road users, road accidents and disasters, destruction of infrastructure, etc.

The organization of transport is the need to take into account specific conditions. Such issues are highlighted by, among others: Behrends, Lindholm, Woxenius [3], or Visser, Van Binsbergen, Nemoto [34]. The important factors conditioning the implementation of the distribution process that must be taken into account are, among others:

- variable travel time through connection,
- restrictions on vehicle traffic due to the permissible gross weight,
- restrictions of the vehicle's movement that do not meet specific emission standards,
- parking spaces or separate areas to stop the vehicle for the time of carrying out the load works at the recipient;
- excluding road connections from traffic due to repairs or other events, eg accidents, demonstrations, mass events.

One of the important issues is the quality of the delivery process. Quality assessment is a specific and difficult issue. Different indicators and methods may be used for quality assessment, including, for example, different methods or unique criteria [20, 36]. The main problem in quality assessment is the fuzzy nature of the assessment criteria and the difficulty in their accurate identification.

Due to different part of the day, rush hour, accidents, infrastructure maintenance, events, the travel time may be radically different, and it is much more difficult to achieve on-time delivery. In the case of cargo transport, transshipment points that allows for cargo operations at the customer, are also important. In a large number of cases, there are no such places to safely and quickly unload the cargo, and this also affects the time of transport. Considerations of cargo distribution depending on the area where it is performed and customer requirements cause the need for carriers to apply solutions that increase the efficiency of transport, including planning and optimization of the transport process or telematics systems.

3. Selected optimization problems and methods of their solution in cargo distribution

Optimization is particularly important in the issue of supply planning. This issue is mainly based on the problem of routing vehicles (VRP). The problem being solved is the delivery of cargo to customers located in the area served by the distribution center, using many vehicles in a way that ensures the minimum cost of transport. In simple terms, the problem is basically to arrange the order of the visited recipients for each route.

Barnhart and Laporte [2] stated that this problem lies at the heart of distribution processes management. Depending on the constraints and assumptions used, a number of variations of the VRP problem can be distinguished, e.g. CVRP (capcaitated VRP), MDVRP (multi depot VRP), PVRP (periodic VRP), IRP (inventory routing problem), SVRP (stochastic VRP), VRPSTT (VRP with stochastic travel times). These problems have found their interest among many researchers, e.g. Baldacci, Toth and Vigo [1], Erdoğan and Miller-Hooks [9], Laporte [26], Schneider, Stenger and Goeke [30].

Recently, as quite significant groups of problems, due to the real problems of VRP, i.e. Real-World or Rich VRP, can be indicated MOVRP and GVRP. Adding additional assumptions to them allows for a good imitation of real systems functioning and real decision problems.

MOVRP (multiobjectives VRP) is a group of problems in which finding solutions is assumed due to different criteria. It is connected with the necessity of using multi-criteria optimization methods, which makes it difficult to search for solutions. However, these types of problems allow for taking into account many points of view and interests of various participants in the distribution process. MOVRP is a frequent and important component of real VRP problems. Modifications and developments of this problem take into account many variants, including assumptions about the randomness of model parameters or heterogeneous transport fleet. The literature on this problem is very diverse and many studies can be pointed out, for example, Ghannadpour et al. [14], Jiang et al [23].

GVRP (Green VRP) a relatively new group in the VRP family, which assumption is to include ecological criteria in the planning of deliveries. A comprehensive review on this type of problem has been presented by Demir, Bektas, and Laporte [8]. They show the diversity of models in it (for example COPERT) taking into account fuel consumption or emission of harmful substances depending on various vehicle parameters and routes. There is also a large diversity in VRP assumptions, from CVRP through VRPTW and SVRP to MOVRP. The inclusion of many criteria is of particular importance when looking for a compromise between the vehicles used and the costs incurred. One-criterion problems are often based on the minimization of fuel consumption and the same cost associated with it. It may also be considered to use electric vehicles with the planning of battery charging operations. Among the most important works in which GVRP is discussed, can be indicated, for example Felipe et al [10], Juan et al [24], Schneider, Stenger and Goeke [30].

The problem of routing vehicles is based on the traveling salesman problem which belongs to NP-difficult problems. Therefore, VRP type problems also belong to this class of problems. For such decision problems, heuristic methods are used, which find sub-optimal solutions. They allow determining solutions acceptable from the perspective of the decision maker with the rational resources used to search for it. Such methods include heuristics dedicated to a specific problem and metaheuristics that are universal methods for solving optimization tasks. Among the algorithms most often used to solve the VRP problem are the branch and bound, heuristic (heuristic construction and route improvement, clustering), metaheuristics (genetic and ants algorithms, taboo search, neural networks) [4, 27]. An exemplary classification is shown in Fig.2.

The exact methods belong to the group of methods that allow to determine the value of decision variables, at which the criterion function reaches the extreme. These methods are used in problems of low complexity. There are many studies in the literature in which such methods are used to solve the VRP. Mainly they are based on the Branch and Bound and its modification Branch and Cut, Branch and Price (Fukusawa et al [12], Toth and Vigo [32]). Among exact methods, can be indicated for example dynamic programming (Gromicho et al [16]). The exact methods are used for simple VRP variants such as CVRP, VRPTW, OVRP, but the number of vertices in the problem cannot be large.

The second group of methods are heuristic methods. They allow to find a suboptimal solution, that is, a solution acceptable from the perspective of the decision maker and the designated resources to obtain it. These are specialized methods that are designed to solve a specific problem or group of problems. Among the known heuristics to solve the VRP, one can indicate the Saving algorithm, the Sweep method, Cluster First - Route Second, Intra-Route Improvement or SERR (Selection, Extraction, Recombination, and Reallocation). Heuristic methods allow for solving more complex problems than exact methods (Dell'Amico et al [7], Felipe et al [10]).

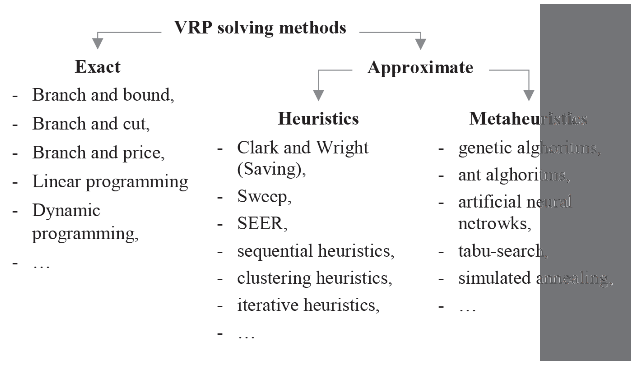

Fig. 2. Classification of optimization methods in VRP [own study based on [11, 29]]

Metaheuristic methods are universal methods, and just like specialized heuristics, returned solution is suboptimal. Their important feature is the ability to apply to a wide variety of problems. Metaheuristic methods include simulated annealing, taboo search, ant algorithms, neural networks and genetic algorithms. The use of algorithms from the above groups is most commonly found in the literature for solving complex problems (Golden, Assad and Wasil [15], Karakatič and Podgorelec [25], Modares, Prins [27]). Often, metaheuristic methods supported by other optimization methods are elements of the so-called hybrid methods.

4. The concept of a decision support system with a quality criterion

4.1. Assumptions of the optimization model

The basis of the decision support system is the mathematical model together with the elements that make up the optimization task. This task is defined by the needs of the decision maker. Depending on the needs, decision-making criteria, decision variables and restrictions imposed on the set of solutions, are defined.

Among the main issues that have been taken into account in the construction of the mathematical model of cargo distribution can be indicated, among others: the availability of infrastructure, the stochastic nature of the traffic process and economic factors. It was assumed that deliveries will take place in a multi-level structure (Fig. 3), ie, deliveries will be made to customers from DC using HUB reloading or directly from DC. At the same time service areas are selected dynamically depending on the needs. This approach to the distribution system makes it possible to reduce the transport work carried out by high-volume vehicles, in favor of delivery vehicles [31]. The decision problem concerns determining the plan of cargo distribution to recipients (clients).

It was assumed that the main objective of the decision support system would be a rational (relative to the decision maker) planning of deliveries, resulting from the clients' demand. In connection with the implementation of the goal, it is necessary to:

- identification of DCs, transshipment HUBs and recipients (customers) and their location on the transport network,
- determination of transport means at the disposal of DCs and HUBs,
- determination of parameters characterizing both DCs and HUBs, delivery vehicles, as well as transport connections,
- defining the size of tasks to be carried out, the size of the needs of recipients (clients),
- development of a cargo distribution system - determination of a cargo delivery plan - ensuring the implementation of all tasks, all reported and accepted delivery needs.

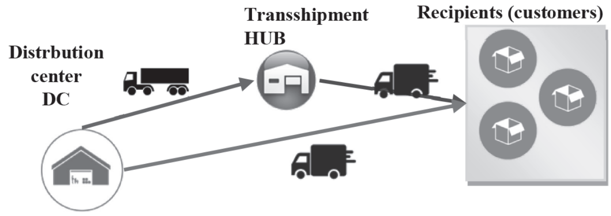

Fig. 3. The cargo distribution system with the use of DC and HUB [own study]

The model used in the decision support system is defined by the following elements:

- the structure of the transport network presenting the layout and connections of the line and point infrastructure (connections between all participants in the distribution process, i.e. DC, HUB and the recipient),
- characteristics of elements of the transport network (characteristics defined on the nodes and connections of the transport network),
- characteristics of the distribution system elements (characteristics of participants in the distribution process),
- means of transport (vehicles) and drivers, along with the characteristics that are at the disposal of DC and HUB, used for the carriage of goods,
- distribution system tasks resulting from the size of reported customers' needs,
- organization understood as a way of delivering to recipients located in the city area, i.e. to set a delivery plan.

Decision support requires determining the criteria for solution assessment. In the optimization process, solutions are determined which are assessed against defined criteria. In the proposed decision support system a multicriteria approach is used in the pareto sense (the decision-maker determines which criteria and to what extent are important by searching the front of non-dominated solutions), three criteria are proposed in the form of a vector function:

$$F(G1, G2, G3) = \begin{bmatrix} G1(\mathbf{DV}) & \longrightarrow \min \\ G2(\mathbf{DV}) & \longrightarrow \min \\ G3(\mathbf{DV}) & \longrightarrow \max \end{bmatrix} \quad (1)$$

where:

G1(**DV**) – the criterion function regarding the costs of the distribution plan,

G2(**DV**) – the criterion function regarding the time of delivery plan,

G3(**DV**) – the criterion function regarding the probability of serving all customers (quality criterion).

For the needs of DSS, it is necessary to define decision variables (**DV**). Due to the multifaceted nature of the problem, there are several types of decision variables, i.e.:

1. variables defining the quantity of cargo units delivered to given objects during r-th run ($r\in\mathbf{R}$), and they belong to the set of non-negative integers, where variables:
   - xnh(r,n) quantity of load units leaving DC with n number, during r-th run between n-th DC ($n\in\mathbf{N}$) and h-th HUB ($h\in\mathbf{H}$),
   - xno(r,n) quantity of load units leaving DC with n number, during r-th run in transport to recipients ODB ($o\in\mathbf{O}$),
   - xho(r,h) quantity of load units leaving HUB with h number, during r-th run in transport to recipients ODB ($o\in\mathbf{O}$),
   - xoq(r,o) quantity of load units delivered for recipient with o number o, durinig r-th route,
2. xt(r) variables specifying the start time of *r*-th run. This is understood as the start of the vehicle loading. Variables were written as a vector where elements belong to the set of non-negative real numbers,
3. binary variables z(r,s,k) assigment to r-th run driver k-th class ($k\in\mathbf{K}$) and vehicle s-th type ($s\in\mathbf{S}$).
4. y(r,l,t) specifying the number of passes using l-th connection ($l\in\mathbf{L2}(r)$) during r-th run in t-th part of the day ($t\in\mathbf{T}$), belong to the set of non-negative integers.

The first criterion function is the cost of the distribution plan– G1(**DV**), which value is minimized:

$$G1(\mathbf{DV}) = \left[G11(\mathbf{DV}) + G12(\mathbf{DV}) + G13(\mathbf{DV}) + G14(\mathbf{DV})\right] \qquad \textbf{(2)}$$

includes:

- fixed and variable costs of storage and reloading facilities, including unit costs for DC (*dc_cst(n)* – unit constant costs, *dc_czm(n)* – unit variable costs (depending on the flow volume) and analogically for HUB i.e. *hub_cst(h)* and *hub_czm(h)*:

$$G11(\mathbf{DV}) = \left[\sum_{n\in\boldsymbol{N}}\left[\begin{array}{l} dc\_cst(n)\,\mathrm{sgn}\left(\sum_{r\in\boldsymbol{R}}\left(xnh(r,n)+xno(r,n)\right)\right)+ \\ dc\_czm(n)\left(\sum_{r\in\boldsymbol{R}}\left(xnh(r,n)+xno(r,n)\right)\right)\end{array}\right]+ \\ +\sum_{h\in\boldsymbol{H}}\left[hub\_cst(h)\,\mathrm{sgn}\left(\sum_{r\in\boldsymbol{R}}\left(xho(r,h)\right)\right)+hub\_czm(h)\left(\sum_{r\in\boldsymbol{R}}\left(xho(r,h)\right)\right)\right]\right] \qquad \textbf{(3)}$$

- penalty for improper handling of the recipient (*odb_ck*(o) – penalty cost per 1 unit of time and 1 unit of charge), calculated when the service occurred before the time window (*α(r,o)*=1, *χ(r,o)*=0) or after the time window has ended (*α(r,o)*=0, *χ(r,o)*=1), in addition, it is assumed that the time is calculated in relation to the start of the run (*xt(r)*), the moment of arrival during the run to the recipient (*TPP(r,o)*) and the beginning and end of the time window (*odb_tws(o)* and *odb_twe(o)*):

$$G12(\mathbf{DV}) = \sum_{o\in\boldsymbol{O}}\left[odb\_ck(o)\left(\begin{array}{l}\sum_{r\in\boldsymbol{R}}\left[\begin{array}{l}\alpha(r,o)\left(xoq(r,o)\right)\cdot \\ \cdot\left(odb\_tws(o)-xt(\mathrm{r})-\mathrm{Tpp}(r,o)\right)\end{array}\right] \\ \sum_{r\in\boldsymbol{R}}\left[\begin{array}{l}\chi(r,o)\left(xoq(r,o)\right)\cdot \\ \cdot\left(odb\_twe(o)-xt(\mathrm{r})-\mathrm{Tpp}(r,o)\right)\end{array}\right]\end{array}\right)\right] \qquad \textbf{(4)}$$

- fixed and variable costs of drivers employment - unit costs *kc_czm(k)* depending on the time worked by the driver *Tpk(r,s,k)* and constant cost *kc_cst(k):*

$$G13(\mathbf{DV}) = \sum_{k\in\boldsymbol{K}}\left[kc\_czm(k)\cdot\left[\sum_{r\in\boldsymbol{R}}\sum_{s\in\boldsymbol{S}}\left(z(r,s,k)\cdot\mathrm{Tpk}(r,s,k)\right)\right]+kc\_cst(k)\cdot\sum_{r\in\boldsymbol{R}}\sum_{s\in\boldsymbol{S}}z(r,s,k)\right] \qquad \textbf{(5)}$$

- costs of run resulting from the distance made by vehicle - *dist(l)* and unit cost of vehicle *sc_czmp(s)*, and fixed costs of vehicle involvement *sc_cstt(s)*:

$$G14(\mathbf{DV}) = \sum_{s\in\boldsymbol{S}}\left[sc\_czmp(s)\cdot\left[\sum_{r\in\boldsymbol{R}}\sum_{k\in\boldsymbol{K}}\left(z(r,s,k)\cdot\sum_{l\in\boldsymbol{L2}(r)}dist(l)\right)\right]+sc\_cstt(s)\cdot\sum_{r\in\boldsymbol{R}}\sum_{k\in\boldsymbol{K}}z(r,s,k)\right] \qquad \textbf{(6)}$$

The second criterion function $G2(\mathbf{DV})$ has an interpretation of the total time needed for customer service. It is the sum of expected values $\mathbb{E}$: travel times $\mathbb{E}\left(\mathrm{TJ}(l,t)\right)$ and loading Times in DC $\mathbb{E}\left(\mathrm{TL\_DC}(n)\right)$ and HUB $\mathbb{E}\left(\mathrm{TL\_HUB}(h)\right)$ and recipients $\mathbb{E}\left(\mathrm{TL\_ODB}(o)\right)$, this function tends to a minimum:

$$G2(\mathbf{DV}) = \\ \sum_{r\in\boldsymbol{R}}\sum_{s\in\boldsymbol{S}}\sum_{k\in\boldsymbol{K}}\left[\begin{array}{l}\sum_{l\in\boldsymbol{L2}(r)}\sum_{t\in\boldsymbol{T}}\left[\mathbb{E}\left(\mathrm{TJ}(l,t)\right)\cdot y(r,l,t)\right]+\sum_{n\in\boldsymbol{N}}\left[\mathbb{E}\left(\mathrm{TL\_DC}(n)\right)\cdot xno(r,n)\right]+ \\ \sum_{h\in\boldsymbol{H}}\left[\mathbb{E}\left(\mathrm{TL\_HUB}(h)\right)\cdot xho(r,h)\right]+\sum_{o\in\boldsymbol{O1}(r)}\left[\mathbb{E}\left(\mathrm{TL\_ODB}(o)\right)\cdot xoq(r,o)\right]\end{array}\right] \qquad \textbf{(7)}$$

The third partial function of the criterion is $G3(\mathbf{DV})$ with the interpretation of the probability of servicing all recipients. The value of this function will be maximized. This function assumes that the unserved recipient is one whose service will not be started before the service time limit has been performed so far and thus the recipient's demand will not be fully satisfied. In connection with the above, an unserved client is also one whose demand has been met only in a certain part. It was considered that this function is a good reflection of the quality of services. The basis for determining this function is the probability that the sum of travel times and loading operations for each customer will not exceed the service time limit (*odb_twk*(*o*)). This value is determined on the basis of left-truncated normal distribution (hence the boundary of integral *tj_min*(*r,o*) with a value corresponding to the least possible travel time) travel times with an average value $\sigma\_\mathrm{Tpp}(r,o)$ and standard deviation $\mu\_\mathrm{Tpp}(r,o)$:

$$G3(\mathbf{DV}) = \prod_{r\in\boldsymbol{R}}\left[\prod_{o\in\boldsymbol{O1}(r)}P\left(\mathrm{Tpp}(r,o)\le\mathrm{odb\_twk}(o)\right)\right]=\prod_{r\in\boldsymbol{R}}\left[\prod_{o\in\boldsymbol{O1}(r)}\int_{tj\_\min(r,o)}^{\mathrm{odb\_twk}(o)}f(u)du\right]= \\ =\prod_{r\in\boldsymbol{R}}\left[\prod_{o\in\boldsymbol{O1}(r)}\int_{tj\_\min(r,o)}^{\mathrm{odb\_twk}(o)}\frac{1}{\sigma\_\mathrm{Tpp}(r,o)\sqrt{2\pi}}e^{\left(\frac{-(\mathrm{u}-\mu\_\mathrm{Tpp}(r,o))^2}{2\sigma\_\mathrm{Tpp}(r,o)^2}\right)}du\right] \qquad \textbf{(8)}$$

The following constrains have been formulated for the problem of distribution planning**:**

- in the distribution plan, each customer must be designated for handling and them demands must be met,
- a given recipient can be visited only once during the implementation of the following run,
- the volume of deliveries leaving DC to HUBs must be equal to the volume of deliveries leaving the HUBs,
- the number of loads leaving DC must be equal to the demand of the recipients,
- the load capacity of the vehicle on the route cannot be exceeded,
- a vehicle leaving DC or HUB must return to it,
- the driver's working time cannot be exceeded,
- the driver's driving time cannot be exceeded,

- the vehicle performing the transport on a given run in a given relation must be of the appropriate type,
- the driver should be in the right category,
- only one vehicle and only one driver can be assigned to a given run,
- service must start before the service deadline,
- the travel time to the recipient cannot be shorter than that resulting from the maximum permitted speed on the sections to be travelled,
- the time of the start of the time window must be smaller than the moment of its completion, while the deadline of service must be greater than or equal to the time when the time window ends.

4.2. Procedures of the decision support system

The developed method of multi-criteria decision support concerns on the determination of a plan of cargo delivery from DC to recipients located in various areas. As indicated earlier, deliveries can take place both directly and indirectly with the use of HUBs. The main objective of the method is to solve the formulated optimization task. In addition, this solution should be included in the set of permissible solutions and therefore meet the imposed boundary conditions of the task (constrains). The method was divided into three stages. The general scheme of the method is presented in Fig. 4.

The first stage of the method involves collecting input data for calculations. In order to solve the task, it is necessary to prepare input data, including data of transport network characteristics, distribution system, data of demand for cargo transportation, as well as boundary conditions of the distribution process. After its completion, the second stage follows, ie the determination of the delivery plan.

In the second stage, the formulated optimization task is solved. This means that it is necessary to solve the VRP task and the task of determining routes in the transport network and assessing the solutions. The second stage was divided into two phases:

- the preparation phase, related to downloading data and preparation for calculations, as well as input calculation parameters for algorithm,
- the computational phase, during which the delivery plan is determined together with the assessment of the acceptability of the solution and the determination of the value of the criteria function.

In the calculation phase, two methods of solving the above-mentioned tasks were included, namely the SPEA2 [37] and A-star methods. The first one concerns the determination of a delivery plan from DC to HUB, from DC to the recipient and from HUB to the recipient. It is necessary to plan deliveries by specifying the start time of the route, the order of the recipients to be visited and the size of delivery, as well as choose the vehicle type and driver class bearing in mind the limitations related to, among other things, transport time, vehicle capacity and driver's working time. The second one is connected with determining the path in the transport network between elements of the distribution system in accordance with the designated delivery plan. The computational phase completes the evaluation of the solution and checking the boundary conditions and the stop condition of the algorithm. If the above conditions are met, the third stage follows.

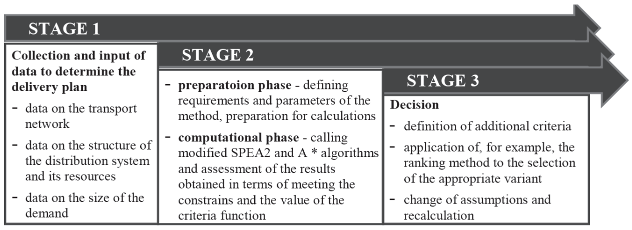

Fig. 4. Stages of the procedure in the developed DSS [own study]

In the third stage, the obtained results are analyzed. In this stage, the evaluation phase was determined by verifying and validating the obtained results. In addition, the essential element of the third stage is interaction with the decision maker. The method is intended to assist the decision maker in making decisions. Therefore, each time the quality of the designated solution should be determined and it should be checked whether it meets expectations and whether it is satisfactory. Organizing the distribution process is an iterative process and may require the decision maker to modify the input data or to adjust the parameters of the calculation method depending on the results obtained.

4.3. Example calculations on the real object

In the considered example, the city's transport system was adopted. On the outskirts of the city, there are 2 cargo distribution centers - DC. In areas designated for industrial development, transshipment points (4 HUBs) have been located. Within the city (Warsaw, Poland), recipients from various industries and with different demand were identified (48x recipient). Fig. 5 shows a map with elements of a multi-level distribution system. In addition, 11 different types of cars (gross vehicle mass from 3.5 to 40) were chosen for the implementation of tasks; and suitable drivers divided into categories up to 3.5 t and more than 3.5 t (GVM). There are 8720 (ujł), standard cargo units, for transport.

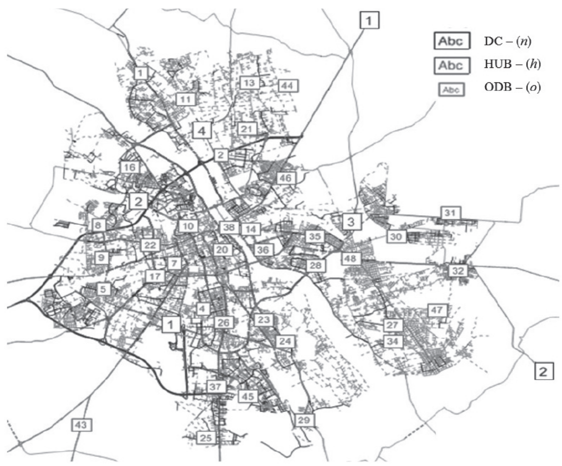

Fig. 5. Transport network and elements of the distribution system in the calculation example [own study]

The calculation example was implemented in four variants,

- variant 1 - single criterion optimization - cost criterion
- variant 2 - single criterion optimization - time criterion
- variant 3 - single criterion optimization - probability criterion (quality criterion)
- variant 4 - multicriterial optimization (pareto, criteria weight cost 0.4, time 0.3 probability 0.3)

The results obtained are presented in Table 1. The advantages of using a multicriteria approach are worth emphasizing. Thanks to the optimization of the three criteria, we are able to significantly increase the assessment of the solution in relation to the remaining criteria. This approach allows to design solutions with much higher quality.

Table 1. A summary of the results obtained with the use of the DSS [own study]

	Variant I	Variant II	Variant III	Variant IV
Number of runs	13	23	24	15
Length of runs in total (km)	1542,87	1820,17	2108,22	1594,38
Average length of the run(km)	118,68	79,14	87,84	106,29
The average transport cost (PLN)	1,45	2,2	2,3	1,52
G1 Cost of delivery plan (PLN)	12644	19184	20056	13254,4
G2 Total time of deliveries (h)	92,93	81,01	82,43	82,71
G3 Probability of correct delivery realization	0,7612	0,9121	0,9720	0,9345

5. Conclusion

Decision support systems are an inseparable element of any logistics company. This article presents the importance of a multicriteria approach to the problem under consideration. Relying on superficial criteria may lead to making wrong decisions in the form of their effects in other areas. Therefore, it is necessary to take into account as many factors as necessary for the decision. The approach presented at work is a sustainable approach that takes into account the entrepreneur, but also the clients.

The presented calculation example indicated that the inclusion of three criteria means that during the optimization we can get worse results than consider each criterion individually. However, worse results relate only to the comparison with the criteria according to which the decision is made. Looking at the whole, it can be seen that the variant of multi-criteria optimization is definitely better. The slight deterioration of each criterion gives a much better result overall. If we would like to introduce multi-criteria pareto functions to one function according to the adopted weights, it would definitely achieve the best result.

The proposed decision support system was presented on the example of a city that is a specific area and requires specific conditions to be taken into account. In subsequent works, for example, the ecological criterion of pollutant emissions will be taken into account, which in the case of urban areas is particularly important for the health of inhabitants. It will also be necessary to consider the dynamics of the urban transport system and random variables characterizing such a system.

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